AMSAT

THE RADIO AMATEUR SATELLITE CORPORATION

PROCEEDINGS OF THE

AMSAT-NA

William A Tynan W3XO Memorial Space Symposium and AMSAT-NA Annual Meeting

November 2 - 4

2018

Huntsville, Alabama

AMSAT®

RADIO AMATEUR SATELLITE CORPORATION

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Welcome to Huntsville!

It is with great pleasure that I personally welcome you to the 2018 AMSAT Space Symposium and Annual Meeting. This is the 36th Symposium, reflecting a long tradition (started in the early 1980's) to provide an annual forum for amateur satellite enthusiasts to gather and share their ideas. AMSAT is proud of the technical content of the papers presented over the years reflecting the inventiveness of our volunteers and the significant contribution of presenters to "advancing the radio art." The word amateur comes from the Latin root "amare" meaning "to love". So amateur radio literally means to love the radio art, and the Radio Amateur Satellite Corporation means the Corporation of the lovers of the radio art with spacecraft.

Holding our Symposium at the US Space and Rocket Center this year is certainly fitting given that Huntsville and the Marshall Space Flight Center are known for the frontier that was created by individuals who forged new paths and created new opportunities in Apollo missions to the lunar surface. Likewise, AMSAT's pioneering innovation in small satellite design and applications for amateur radio and science is also well recognized. We expect our last two Fox-1 class satellites to be in orbit within the next six months, each with their own personality and orbital characteristics. Fox-1Cliff is currently scheduled for launch before the end of the year from Vandenberg AFB, CA as part of AMSAT's funded commercial launch participation on the Spaceflight SSO-A mission from Vandenberg. Again, as with AO-91, this satellite will feature an L-Band uplink capability, as well as, a camera system built by Virginia Tech. RadFX-Sat-2/Fox-1E is part of the ELaNa-XX launch and features a new linear transponder now expected to fly in First Quarter 2019.

Fox-1D, now AO-92, was also a commercial launch arranged by Spaceflight, Inc. flying on a PSLV (Polar Satellite Launch Vehicle) launched earlier this year from India. In addition to the launch of RadFxSat, now AO-91, launched late last year, AMSAT now has 3 operational FM CubeSats currently in orbit. As is AMSAT's tradition, this edition of the Proceedings contains details about our satellite designs that we're placing in the public domain through formal publication. We're releasing these materials so that we may openly discuss our spacecraft development efforts in public, as well as, our desire to encourage greater use of amateur radio in space, and to provide a foundation for other institutions to utilize our design. This edition of the Proceedings is also dedicated to our friend, William "Bill" Tynan, W3XO(SK), who passed away earlier this summer.

There are other flight opportunities for AMSAT's comm package that are being developed. "An OSCAR in every university CubeSat" that further enhance amateur radio's presence in space while supporting scientific payloads. Other AMSAT projects include ARISS (Amateur Radio on the International Space Station) IORS (Inter-Operable Radio System), the engineering work on the GOLF (Greater Orbit, Larger Footprint) 3U series of CubeSats, and a CubeSat Simulator for Educational outreach.

Meanwhile, the 36th AMSAT Space Symposium provides an opportunity to discuss the above and our next generation of projects. The ground terminal development work has been discontinued by AMSAT

and has moved into the open source community. ASCENT (Advanced Satellite Communications and Exploration of New Technology) development program continues to help our engineers to develop new technology. AMSAT is collaborating with an Industrial provider for up to 3 ADAC (Attitude Determination and Control) packages for the AMSAT-built GOLF HEO (Highly Elliptical Orbit) satellite and always exploring opportunities for a Geostationary ride should such an opportunity arise.

After forty-nine years, we continue to develop remarkable satellites with educational outreach and scientific benefit that provides the basis for fulfilling AMSAT's mission. That mission is about to celebrate its fiftieth year, so look for special events throughout next year. The future is space and AMSAT is there and will continue to be. Your support will help to ensure a bright future for lovers of the spacecraft radio art.

73,

Joseph K. Spier, K6WAO

President

It is with great sadness that AMSAT reports the passing of one of its founding directors and charter members, William A. (Bill) Tynan, W3XO.

Bill passed away peacefully at his home on Tierra Linda Ranch in Kerrville Texas, on August 7, 2018. He was 91. Bill was born October 12, 1926 in Saint Paul, Ramsey County, Minnesota. Throughout his adult, life, he left an indelible mark on Amateur Radio with a long list of "firsts" since becoming licensed as W3KMV in early 1946. Indeed, Bill was in the forefront of Amateur Radio's growth and importance in many ways. His singularly distinctive accomplishments to our Radio Service were, quite literally, "out of this world."

His Amateur Radio interest began when he acquired a Philco shortwave radio as a young boy in the mid 1930s. During the Second World War, after obtaining a Restricted Radio Telephone Permit, he operated in the War Emergency Radio Service (WERS), donating his time and effort to the citizens of Montgomery County, Maryland and later to the District of Columbia by operating WERS systems on 2 1/2 meter VHF (then called UHF). Of course, this occurred during a time when all Amateur Radio activity had been suspended for the duration of the War.

His wartime activity would later spark his interest in the frequencies above 30 MHz, and he became an active VHF/UHF enthusiast almost since obtaining his first ham ticket. However, it was his work in helping others exploit the VHF/UHF spectrum that best characterized Bill's numerous accomplishments and contributions to Amateur Radio.

In early 1969 Bill attended the charter meeting in Washington, DC to investigate the feasibility of carrying on the work of Project OSCAR, a group of West Coast Hams that had built and launched the very first satellites carrying Amateur Radio. The meeting led to the establishment of today's Radio Amateur Satellite Corporation (AMSAT). Bill was elected to the first Board of Directors of the new organization, and was later named Vice President for Operations.

The first AMSAT Board of Directors, including Bill Tynan, then-W3KMV (third from the right)

Bill performed yeoman service in this position during the OSCAR 6 era, principally because that particular satellite had a nasty habit of unexpectedly changing operating modes "on its own". Bill's superb efforts coordinated the work of dozens of worldwide command stations to keep OSCAR 6 (then the only OSCAR satellite in orbit) up and running for the world's Amateur Radio Operators. His outstanding work allowed critical Amateur Radio propagation and other experiments as well as other more routine communications to continue virtually unabated. His singular efforts extended use of a critical space-based experimental Amateur Radio resource that otherwise would have been given up for lost.

Later, Bill's strong reputation for getting things done, and his expertise as a leading expert in the VHF/UHF arena, led to a request from the American Radio Relay League (ARRL) that he assume duties as Contributing Editor for QST Magazine's "World above 50 MHz" column. Under his superb guidance, and during the next 18 years, Bill kept the column both fresh and alive, while providing Hams worldwide with a powerful forum to advocate and nurture such new Amateur Radio technologies as long-haul VHF/UHF, moonbounce, DX and contest work, as well as emerging meteor scatter and satellite communications.

However, while Bill Tynan's first love was VHF and UHF work, his heart and soul were always with AMSAT. Not surprisingly, it is with AMSAT that Bill's positive impacts on Ham Radio were destined to become some of his longest lasting contributions to our Service.

For example, since his earliest days in AMSAT, Bill was intrigued with the possibility of Hams on the ground being able to talk to Hams in space. Later, in the mid-1970's, he actively explored the idea of Amateur Radio operation from aboard the Skylab space station while Owen Garriott, W5LFL, was to be a part of that crew. Unfortunately, NASA did not approve this proposal, stating that it was too late to modify the station to provide for an antenna.

However, later, as the Shuttle program was beginning Bill authored the very first draft proposal to allow Amateur Radio operation from the Space Shuttle. His idea was soon picked up by the ARRL, and it resulted in a formal, joint AMSAT/ARRL proposal to NASA to allow this activity. Needless to say, Bill's superb vision led directly to Owen Garriott's historic first use of Ham Radio from space during the STS-9 mission, thus marking the birth of the very popular SAREX program.

In 1986, Bill was again elected to the AMSAT Board of Directors, and, in 1991, just as the Phase 3D project (which later became AMSAT-OSCAR 40 on orbit) was beginning to gain momentum, Bill assumed duties as President of the organization at a most critical period in its history. As with his previous callings, Bill wasted no time in making his lasting mark on the organization. As one of his first efforts, he was instrumental in pulling a team of over two hundred volunteer people from 13 different countries together with the common goal of building and launching the largest, most complex, and most expensive Amateur Radio satellite ever attempted. When he finally stepped down from his post as AMSAT President in late 1998, his repeated, annual re-election to this high post made his one of the longest running terms as President in the organization's history.

In addition to his solid accomplishments in furthering Amateur Radio, Bill remained a very active Radio Amateur. He was a life member of the ARRL, a life member of AMSAT (membership number 10), and was an active member of the Central States VHF Society, also serving on its Board of Directors. He was its President in 1992 and put on the organization's annual conference that year. Bill was also a member of the Quarter Century Wireless Association, the Radio Club of America, the Institute for Electrical and Electronics Engineers (IEEE) as well as the National Space Society. Locally, he was the Program Chairman of the Hill Country Amateur Radio Club at his home on the Terra Linda Ranch in Kerrville, Texas and also served on the ranch's Cable TV advisory committee.

During his lifetime, Bill also received several prestigious awards, including "The Ham of Year" in 1996 from the Dayton Amateur Radio Association (DARA) and in 2012, the Barry Goldwater Amateur Radio Award from the Radio Club of America.

Bill graduated from Rensselaer Polytechnic Institute in 1951 with degrees in Electrical Engineering and Management. In his professional career, he was a Senior Engineer at the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland from 1951 to 1988. Bill worked in APL's Fleet Systems Department where he made critical contributions to the Navy's Tomahawk cruise missile, and he was instrumental in organizing the first annual AMSAT Space Symposium which was hosted by APL in the fall of 1983.

Along with Bob Carpenter, Bill constructed the first FM stereo broadcast station in the Washington DC area, WHFS, in 1961. Since stereo broadcast equipment was not yet commercially available, he had to construct and obtain FCC certification for the station's FM stereo exciter.

Following his retirement, Bill published several novels under the name of W. Almas Tynan, including *Scot-Free: 9/11 Interrupts Their Plan* and *Separate Worlds: A Journey of Discovery.*

Bill is survived by Mattie, his wife of 51 years, along with numerous cousins, brothers and sisters-in-law. *By Keith Baker and Dan Schultz*

Statement of AMSAT President Joe Spier, K6WAO, on the passing of Bill Tynan, W3XO:

I can only second the many comments and condolences that are coming in from around the world on the passing of Bill Tynan, W3XO. From the many remembrances of Bill's past accomplishments, it is clear that AMSAT and amateur radio has lost a dear friend.

Friend is an important way to honor Bill. Bill was a friend to AMSAT, a friend to ARISS, a friend to the ARRL, a friend to amateur radio, a friend to his community, and lifelong friend to his dear wife, Mattie. Bill's friendship extended to me when I became AMSAT President. After hearing me present on some subject, I received a three page treatise from Bill on the proper use of the pronoun "me." His keen ear had picked up on my error, and the improvement came in a paper titled "What's the Matter with Me?"

Bill had a way of looking at issues from a different perspective. Last October's Board of Directors meeting was in the middle of a "heated" discussion on the verbiage of a proposal, when Bill walked in and sat down. After another 15 minutes of discussion, further discussion on the proposal was tabled until the following day. Bill's comment after listening to all this was "Wow, sounds just like the board meetings we use to have 40 years ago!"

Recently, Bill asked to step down as the AMSAT OSCAR Number Administrator. Bill has been granting applicants who qualify OSCAR numbers for over two decades, since the late-1990s. Even Bill could not remember the first number he issued, but he believed it was either TO-31 or SO-35. In any case, Bill had issued at least 57 OSCAR numbers. This is over 60%, or very close to two-thirds, of all the OSCAR numbers currently issued at this time.

Bill liked to keep busy with his passion for amateur radio, whether this was working in the foreground or background. Only a few weeks ago, Bill proposed to AMSAT the use of FT-8 as a digital mode on a future satellite. My friend, Bill Tynan, W3XO, was always thinking ahead.

Ad astra.

What's the Matter with **Me**?
by
William A. Tynan

There is nothing wrong with **me.** The word **me** is perfectly simple. It's just two letters, **m** and **e.** It has a specific use and should be used in the correct manner. There is no reason to substitute another word for it. So, why do so many people do so, even well-educated people? All too often, you hear people say things like, "The teacher gave Joe and **myself** a stern lecture. or "The President of Mexico and **myself** held an hour-long telephone conversation."

Yes, I have heard President Trump say that on television.

In these examples, the person should have said. "The teacher gave Joe and **me** a stern lecture; and

President Trump should have said, "The President of Mexico and **I** held an hour-long telephone conversation."

Why not use **me** and **I** the way they are supposed to be used? My belief is that people use **myself** when they don't know whether to use **I** or **me**.

What kind of the words are **me** and **I?**

They are pronouns.

What is a pronoun?

A pronoun is a word that is used in place of a noun that refers to a specific individual or thing, for example, **he** might replace a specific individual - "the teacher,"

There are twenty-four pronouns in the English language**; I, me, you, he, she, it, we, they, them, us, myself, yourself, himself, herself**, **itself, ourselves**, **themselves, my, your, yours, mine, his, hers** and **its.** Pronouns are divided into three classes, or cases, according to their use. The subjective case singular pronouns, **I**, **you, he, she** and **it,** are used as subjects of sentences. For example, "**I** went to town today." "**She** read the book." The same goes for the plural; **we** and **they**. "**We** went to town today." "**They** read the book." The singular objective case pronouns, **me**, **you**, **him**, **her** and **it** are used as objects of sentences. The teacher read the lessen to **him**. The plural is; the teacher lectured **them**. The singular reflexive pronouns, **myself**, **yourself**, **himself**, **herself** and **itself** are used to denote an action back on the subject. I hurt **myself**. He killed **himself**. Similarly, the plural reflexive pronouns, **ourselves** and **themselve**s are used to reflect back on more than one person or things. They hurt t**hemselves.**

It is important to use pronouns only when the person or object being referred to is understood. An example of a specific person or thing understood might be, **Joe**, **Mary**, **the book**, etc. One might say, **Joe and Mary** went to a movie last night. Now that the specific persons arei unidentified, the next sentence might be, **They** saw a scary show. The pronoun **they** can be used

since we already know who went to the movie, in this case Joe and Mary. "**I** went to town today." Incidentally, **I** is the one pronoun in which it is not necessary to define beforehand or afterward who is being discussed, since it is obviously to person speaking or writing.

Because pronouns are used, to replace a specific name or names, word or words when specific individuals or things are understood, or will be in succeeding sentences, one would not begin a story or document by something like, "T**hey** had a good time at the party," unless you are going to make it clear in succeeding sentences who **they** are. Doing so would leave the reader wondering who you're talking about. Generally, this is done as in the example of Mary and Joe going to a movie and the fact that **they** saw a scary show.

If the thing one is referring to is an inanimate object such as a **book** or **house**, or **a living thing,** the gender of which is undetermined or of little consequence, one uses the pronoun **it** to refer to that object, animal or plant. "The snake went back into the hole. I am glad **it** is gone."

The pronoun **us** is objective. The teacher gave **us** his opinion. **Us** went to town, is wrong and you don't hear it very often, but, all too often, you do hear, "**Me** and **him** went to town. It sounds awful and it's wrong because **me** and **him** are objective pronouns and are used as objects of a sentence, not the subjects. The sentence, "He gave the books to **me** and **him**." sounds bad, but is correct grammatically. It would be better to name a specific individual, **John,** rather than using, **him**. "He gave the books to **John** and **me,"** is better form.

I haven't yet covered second person pronouns. The second person pronoun **you** is both subjective and objective so it is used for both the subject of a sentence and the object of a sentence and can be singular or plural. An example of **you** as a subject is "**You** must have studied the lesson." "I am telling **you** to study the lesson," the teacher said, "is an example of **you** being used as an object of a sentence and it can refer to a single student or the entire class.

It must be tough for foreigners to learn English.

The word **they** is the plural third person subjective pronoun. "**They** went to a movie." The word t**hey** is the subject of the sentence. The objective equivalent is **them**. It is hoped that you wouldn't say or write, "**Them** went to the movie." You would say or write, "The move pleased **them**." Like the pronoun **you,** the pronoun **it** is used in both the subjective and objective cases. Thus, one can say or write "**It** is cold outside." The pronoun **it** is the subject of the sentence and refers to the weather. This is another case in which it is not customary to have define what **it** is. An example of **it** being used as the object of the sentence might be, "When the snake comes out of the hole, I will kill **it**." If the snake has already been referred to in a previous sentence, once could say, "If **it** comes out of the hole, I will kill **it.**

The same principal applies to the plurals. They hurt **themselves.** Since they did it to themselves, it is reflexive.

All of this brings me to why I am writing this piece. It is to illustrate one of my pet peeves, namely the use of reflexive pronouns when either subjective or objective pronouns should be used. As I said, a reflexive pronoun should be used to reflect back on the subject. As the name

implies, it is something that reflects back on the person or thing that is the subject of the sentence. “I hurt **myself,**” is a perfect, example. **I** is the subject of the sentence, relating to something being done by the person saying or writing the sentence, to that same person. The most common misuse of the reflexive pronoun, **myself** is typified by a sentence such as, “As for **myself,** I prefer to watch sports on television.” The correct phraseology is, “As for **me,** I prefer to watch sports on television.” - the objective case after the preposition, **for**. The objective case is always used after a preposition such as **for**, **to**, **from, on**, **under,** etc. Even worse, in my opinion, is the common use of **myself** as an object, or even the subject, of a sentence. “**Joe** and **myself** are going to a movie tonight.” In this case, the subjects of the sentence are Joe and **myself.** Of course, the sentence should read, Joe and **I** are going to a movie tonight. The easy way to determine what sounds right is, just take out the other party away, in this case, Joe**.** You can immediately hear that “**Myself** is going to a movie sounds wrong and, of course, it is. Obviously, the correct sentence would be, **I** am going to a movie.” (I won't get into the various verb conjugations such as **is, am,** and **are** That is the subject of another article.)

So, let’s stop using **myself**, in place of **I** or **me.** There's nothing the matter with **me** when it is the appropriate pronoun to use. The same goes for **himself**, **herself** and **itself.** Use them where they are supposed to be used, an action reflected back on the person(s)

I am sad to have to pass along the news that one of our AMSAT Engineering volunteers, Neal Reasoner, KB5ERY passed away in February. Neal was a relatively new member of the team, and brought his expertise in FPGA programming to ASCENT and ultimately to GOLF but for a short while, in working with the SDR design that we had in mind for GOLF and beyond. Neal lived in Austin, Texas and found out about our work through his father Harold Reasoner, K5SKX of Fort Worth, who introduced us. Thank you for volunteering and being a part of our team, Neal. SK de N0JY. *By Jerry Buxton*

Neal was born April 1, 1974, in Fort Worth to Harold and Jodie Reasoner. He graduated from Western Hills High School in 1992. Neal earned the rank of Eagle Scout in Troop 95 in Benbrook in 1992, and backpacked with his troop at Philmont Scout Ranch in 1992. Neal graduated from Texas A&M University in College Station in 1997 with a Bachelor of Science Degree in Electrical Engineering. While at A&M, Neal participated in Aggie Bonfire construction and was a crew chief for Puryear Hall. Neal remained a big fan of Aggie football throughout his life. After graduation, Neal was employed at Texas Memory Systems in Houston, Active Power in Austin, and Flex Radio Systems in Austin. He also did consulting work for several companies. An active ham radio operator, Neal designed and developed electronics and software that is used in repeater systems throughout the southwest United States.

AMSAT's GOLF Program

Jerry Buxton, NØJY

Vice President – Engineering

The Fox program was split into two paths early on, with the demise of AO-51 bringing about a challenge to get a replacement to orbit with similar capability and as soon as possible. Thus, Fox-1 became the project for a simpler CubeSat than the overall Fox idea originally being worked, and that would be followed by a future Fox-2 to fulfill the ideas being developed. Fox-1 quickly became a popular platform for launch opportunities for a growing number of interested partners, resulting in all four planned Fox-1 flight models being built in about a two-year span. Fox-1E was added to the family because of "popular demand".

Serious discussion of the next satellite design resumed in 2016 amongst some of us who had the opportunity to be together for Fox-1 events such as environmental testing. Presented with a fair amount of time sitting around waiting during the tests, we talked about the future of Fox-2. We worked with ideas from the original Fox thoughts, Eric Skoog's 2015 *Future Fox* paper submitted in the *Design the Next AMSAT Satellite* challenge, our experience with the Fox-1 CubeSats, and current our abilities, opportunities, and desire to return to HEO. Over time, these ideas were further expanded by research and development that ASCENT had been working on including some of the design that had been done for the "CQC" project (a.k.a. Phase 5 to AMSAT) that was ultimately eliminated in the project selection process. (ASCENT is the AMSAT Advanced Satellite Communications and Exploration of New Technology "skunk works" program.) From all of this, the shape of what would be next as well as the time elapsed since the first work on Fox led me to move forward with a new program rather than calling it Fox-2.

The name GOLF comes along as we follow the progression of satellite naming that goes back at least 14 years to AMSAT's Echo, which is the phonetic alphabet for the letter E. Upon launch, Echo became AO-51. The next step was Fox, which is the (abbreviated) phonetic foxtrot for the letter F.

The phonetic for the letter G, which is golf, seemed to many of us to be a bit weird for a satellite. We went through several suggestions that sounded more satellite, or aerospace, or majestic, but none of them was a favorite of mine. With the 2017 Dayton Hamvention upon us, I came up with an acronym for GOLF: "Greater Orbit, Larger Footprint" was what I used on the one slide about *Next LEO Satellites (general thoughts)* for the forum. Nobody else knew about it, I figured that I would see what feedback or complaints I got - but nobody complained. By Symposium 2017 neither the AMSAT Board or Officers had taken exception to that acronym so it became official when I presented it for the Board meeting.

And it is quite proper, as the GOLF program calls for a series of 3U CubeSats that call for increased complexity as we work toward HEO in steps, or increments, of both engineering and hardware knowledge and higher orbits. CubeSats pose different challenges in achieving the precise control required for pointing and propulsion than the original HEO satellites, volume being the obvious difference. Physics are the same, however the power requirements and techniques of new hardware are not in our pool of volunteer expertise yet and we do not yet have practical experience with the

command and control necessary. It is the nature of radio amateurs, especially AMSAT engineers, to want to know how to make something work and it is of benefit to AMSAT to be able to operate, troubleshoot, and improve all of the aspects of our satellites. Given the cost for a launch to a HEO type orbit, it is sound reasoning to be sure that what we launch is reliable and understood rather than the first flight of very complex equipment.

There are several things that Engineering would like to achieve in order to be able to again produce HEO-worthy and long life satellites, but in the new CubeSat form factor rather than the relatively much larger designs of our previous HEO satellites. Attitude control, increased power through deployable/steerable solar panels, lower cost radiation mitigation, propulsion, and de-orbit capability are essential to putting a satellite in orbit above about 700 km. While much or all of this capability is available on the commercial market, the cost of even one of these systems can easily be way beyond what AMSAT can afford. More important, in my opinion, is the fact that all of our Engineering volunteers are here to have fun and share their skills in building satellites, not so much to be handed a bag of pre-assembled parts with a manual in five languages and told that we're building a satellite. Innovation and learning are things that will allow us to know how to operate and be able to archive the knowledge for future AMSAT Engineering generations.

Our free time discussions of the next design brought about the stepped approach, with several missions that offered various science opportunities for partners as well as a platform for our experimenting with the aforementioned systems development. Solar power and radios were at the top of the list for the first mission, but an opportunity came along in late summer 2017 that would "jump" us up to the attitude control phase.

Ragnarok Industries, with whom we collaborated in the CQC / Phase 5 opportunity came to us with an offer of a version of their attitude determination and control system (we typically call it ADAC in Engineering) that they were working on for CQC. While we will purchase this system and I cannot comment here on our specific agreement, it is an attractive offer and it includes the opportunity to learn much more about their system such that we gain much more understanding of the design, operation, and control than we would find in "a manual in five languages". In addition, we have the option to acquire the systems for future GOLF missions, which would extend our learning opportunities and enhance our ability to use them.

This jump start led to my presentation and request to the AMSAT Board of Directors at the 2017 Symposium in which I asked for the budget to start work on the "GOLF-T" project in 2018. That name was chosen because this opportunity jumped ahead of the original timeline and progression that we had been laying out for GOLF, hence the "tee off" of the GOLF program. I later changed it to *GOLF-TEE* for the CSLI proposal submitted in November 2017, not having a suitable external explanation for the "-T" I added to the GOLF acronym with "Technology Exploration Environment" which is a pretty good description of how we envisioned the evolution of GOLF, anyway.

And with the Ragnarok opportunity came the thought at Symposium that there might be a way to an orbit up around 1300 km altitude, in the range of FO-29 and AO-7. That thought would require a quick successor to *GOLF-TEE* and so I also briefed the Board while still at Symposium although after the official annual Board meeting, of the need of a 2019 budget estimation above that which I had presented for *GOLF-TEE* alone. With their consensus, I also submitted a CSLI proposal for *GOLF-1* in November 2017.

Both proposals were accepted by NASA in February 2018. Please note that accepted does not mean approved for launch, in truth all CSLI are either accepted into the program or not, and whether and when you get a launch depends on your ranking in the list of accepted proposals and where and when you want to go.

GOLF-TEE will be a (fairly) rapid deployment with two major mission components, one being to test and learn the ADAC system and the other being to test the AMSAT designed and built deployable solar panel array. As such, a few "TRL-9" systems will fly in order to have a failsafe way to communicate with the ADAC and to be able to receive telemetry about the ADAC and solar panel array under test. These systems by default will bring an amateur radio transponder with them, so if the whole thing goes to pot (except some solar and battery power) we have the AMSAT staple, an amateur radio satellite. Those systems for this purpose are the Fox-1E-type IHU, ICR, and transponder. When I say TRL-9 here it is a bit of an optimistic prediction that Fox-1E will launch soon and the IHU, ICR, and transponder will all work! They did when I approved it and sent it off for environmental testing and they did in the post-environmental short functional test, anyway.

In the future systems department we have what we call the *RT-IHU*, which stands for Radiation Tolerant Internal Housekeeping Unit, which you may have heard about and seen some of at Symposium 2017. This started as an ASCENT project and the wonderful progress of the ASCENT engineers with it fit well with the "lower cost radiation mitigation" that I mentioned before. The IHU resets of the Fox-1 series are well known by the public and us, and were expected and handled in the Fox-1 hardware and software design. Future satellites with systems such as ADAC, steerable solar panels, propulsion and so forth will likely require more uptime stability from an IHU and so in following the stepped approach of GOLF, *RT-IHU* is looking toward achieving that. Yes, much higher orbits probably will require much more (expensive) radiation hardening but for LEO, which includes the 1300 km range of *GOLF-1*, *RT-IHU* could fill the bill. Given the resources, both volunteer and money, AMSAT does not intend to abandon LEO projects and there will likely be a few GOLF missions in LEO before we make the stretch to MEO and HEO.

Also in the future systems department is a return to SDR. ARISSat-1 had an SDR, and the original Fox/Fox-2 design was for SDR. SDR is versatile and desirable in many ways, but it is also more susceptible to radiation upsets than the analog radios in the Fox-1 series and can draw much more power than those analog designs depending on the amount of fun you want to have with the signals going in and out of the SDR. While we aspire to design our own SDRs based on FPGA, here too we don't yet have the knowledge and resource base to put one together like we have with the analog radios. *GOLF-TEE* will use a commercial SDR then, with the Ettus B210 being the target as a result of CQC work and development done in ASCENT. There are many questions about the long term function of such a device in space, especially as we go to higher orbits, but here again *GOLF-TEE* is the exploration environment and will provide the opportunity to find out some of the space environment unknowns. It is also the opportunity to learn the use of SDR in a relatively power-constrained environment of a 3U CubeSat with fixed solar panels.

As such, the SDR on *GOLF-TEE* has only one mission objective; to downlink telemetry at a minimum speed of 1 Mbps in the 10 GHz amateur satellite band. This serves as a starting point for handling much more telemetry, useful for both satellite control and experiment results, and for the "Five and Dime" 5 GHz uplink / 10 GHz downlink band plan. "Five and Dime" is the microwave band scheme workd out for

the CQC/Phase 5 transponder and Phase 4B project and it is the expected standard band plan (mode C/x) for future, higher orbit satellites because of the bandwidth available in the amateur satellite microwave spectrum. AMSAT Engineering being the type who don't think small, there are ideas on how to incorporate a possible mode V/x transponder from the standard Fox-1E transponder 2 meter uplink. Stay tuned on that.

GOLF-TEE will also carry a Vanderbilt University low energy proton radiation experiment like those flown on some of the Fox-1 missions. The purpose of the experiment in this mission, beyond being another opportunity for Vanderbilt, is to provide radiation data similar to that gathered by the Fox-1 satellites for a possible comparison to the environments where Fox-1 satellites have their upsets/resets, in studying the operation of the *RT-IHU*.

GOLF-TEE is expected to be ready for delivery and integration by the end of 2019, for a possible 2020 launch. Current plans are to seek an orbit around 650 km altitude, with an inclination between 63 degrees (approximate AO-85 inclination) and 98 degrees (approximate AO-92 and AO-92 inclination).

GOLF-1 is dependent on the development and hopefully, the on orbit performance data of many of the newer *GOLF-TEE* systems. The overall *GOLF-1* primary mission objective is educational, rather than the *GOLF-TEE* overall focus on technology. In that, the primary mission objective is a Vanderbilt University radiation experiment that will be flying at a much higher altitude than those previously flown. As a secondary mission objective, camera experiments including a daylight video and an infrared imager provided Albuquerque Public Schools and built through their Stem Trajectory Initiative in cooperation with Virginia Tech, will be flown.

GOLF-1 has a technology component as a secondary overall mission objective, in continuing development of radiation tolerant systems and SDR, as well as solar power capability. The SDR on *GOLF-1* is expected to be the primary radio system, adding 5 GHz uplink capability for a Five and Dime mode C/x transponder as well as other possible combinations with the 70cm, 23cm, and 13cm bands. With the higher altitude, a general addition to the FO-29 and AO-7 range of contacts is targeted.

The altitude of *GOLF-1* though, is our first incursion into orbital altitudes that will exceed the 25 year maximum lifetime orbital debris requirements imposed by international treaty. That means that we need the capability to ensure that *GOLF-1* either re-enters the atmosphere and burns up, or is moved to a disposal orbit above 2000 km, within 25 years of the end of its mission.

This poses some big challenges, and to even get a launch for *GOLF-1* will require approval by the FCC and satisfaction of NASA as to our ability to meet the requirements. If you are not familiar, the FCC holds the hammer in meeting orbital debris requirements by the fact that they will not issue a license if you do not meet the requirements. We will have to incorporate a reliable de-orbit mechanism, or propulsion, in order to fly.

Given the stepped approach we have planned to take, the de-orbit mechanism will likely be the choice and to that point we plan to include a de-orbit device on *GOLF-TEE* for some practice and knowledge, even though it is not required. Propulsion is both unknown (unless we get some experienced propulsion volunteers real soon!) and expensive. Along with that, the 25 year rule as I generally refer to it, is currently held to mean just that. While the requirement is to comply within 25 years after the end of mission, CubeSats have a pretty long record of having pretty short missions and that has caused the 25

years to be applied literally, as 25 years after launch. While AMSAT has some good examples of missions lasting much longer than one year or so, and in some cases even more than 25 years as in the AO-7 we are seeking to supplement, convincing Washington of that will be an uphill battle.

AMSAT will figure it out if we all, ever, want to leave LEO.

Look forward to more GOLF, at Symposium 2018!

A Look Back at the Fox-1 Program

Jerry Buxton, NØJY

Vice President – Engineering

On July 11, 2018, I gave the Mission Readiness Review (MRR) for RadFxSat-2/Fox-1E in Chantilly, VA. Review panel members from the integrator, TriSept, and our ELaNa launch provider NASA LSP gave the thumbs up to the steps and artifacts that I presented to demonstrate that we are ready for integration and launch.

As such, the last of the Fox-1 series of five CubeSats is officially completed and given the current launch schedules for Fox-1C and RadFxSat-2/Fox-1E, we are near to closing the Fox program that began in 2010. The accomplishment is tremendous, even more so given our all-volunteer "workforce" with over 100 hams involved throughout the course of the program.

And it is the tireless dedication of a core group within those volunteers that has brought the program to a successful conclusion, at least successful in that we have three operating Fox-1 satellites and two that are operationally ready to go. While I have shared some of the activity that goes on in the process of building a satellite through this column, presentations, and my YouTube channel, what you see is the tip of the iceberg in what it takes to put a working and robust satellite designed to last a decade or more into orbit and operating (mostly) nominally. The efforts of the entire Fox-1 team should be applauded by all members and non-members alike, and special thanks given to those who saw (and are still seeing) it through to the end.

Fox-1 was AMSAT's first CubeSat, and in the words of former VPE Tony Monteiro AA2TX (SK) from an article he wrote in 2010, "While AMSAT has pioneered the development of small, low-cost satellites, the CubeSat concept takes this idea even farther (and smaller!) Our AO-51 satellite is a relatively tiny 10-inch cube that weighs less than 25 pounds. A basic CubeSat on the other hand is an even smaller 4-inch cube and weighs less than 3 pounds. AMSAT has adopted the CubeSat idea for our next satellite project to take advantage of the low launch costs. The small size however, does pose some interesting design challenges."

For those of you who have seen the Fox-1 "life size model" at Hamvention or a local hamfest, the size of a 1U CubeSat is amazing and the amount of functionality and space-hardiness that AMSAT crammed into a Fox-1 is a marvel. No less than 9 PCB systems are "carefully crammed" onto their own 4 inch PCB stacked with just 8 mm between the systems. For those of you who are metrically challenged like I am, that's less than 3/8 inch between boards!

Entire systems reside on a single board. From the –Z ("bottom") to +Z ("top") ends of the stack, are the FM transmitter (1A-D) or the full transponder (1E), the FM receiver (1A-D) or the Improved Command Receiver (1E), Integrated Housekeeping Unit (IHU), PSU (MPPT), Battery (taking two PCB levels), and four experiment slots hosting a variety of experiments from both university partners to our own L-band Downshifter.

You might think that the PCB in a modern HT for example, is much smaller than the 4 inch transmitter board in Fox – but when you consider the thermal requirements, radiation effects and shielding, and outgassing properties of components the HT would very likely not last the decade in space that AMSAT designs for. While the cost of a Fox-1 is negligible in the real world of satellites, we all want our satellites to be there and operating as long as possible, right up to re-entry. With the miniaturization readily available and required in CubeSats comes the increased risk of failure due to the aforementioned environment and so we proceed with caution and risk mitigation through the careful consideration of components that will fit the footprint but also provide a margin of risk mitigation to achieve the desired operational lifetime of the satellite. Hence the aversion to a "radio on a chip" which includes all of the systems and is subject to catastrophic failure as one unit, rather than the distributed architecture of the Fox-1.

For example, Fox-1 is designed to work without the IHU. Of course the IHU is highly desired and provides a lot of the function of the satellite from telemetry to the various operating modes to the operation and telemetry of the science experiments. But in the design of things with our first CubeSat it was envisioned, and is being readily seen, that the IHU would suffer upsets in passing through the South Atlantic Anomaly (SAA). Discussion (arguments) ranging from a reset every orbit that passed through the SAA to a reset only once a year were part of the overall design of the IHU software and more so the IHU hardware and its effect on and control over the rest of the satellite. Those of you keeping score have noticed that AO-85 is up to reset 776 as of this writing, where will it be when you read this? That number is greatly inflated with a series of a few hundred resets shortly after launch, but it is extremely regular and actually provides a job and fun for one of our dedicated AMSAT retirees. You can see on a map of the AO-85 resets at http://www.qsl.net/ka2upw/ao85_reset_map.html how the majority clearly occur in the SAA. Please note that the page shows "For development purposes only" as page author Douglas Quagliana, KA2UPW, is in the process of updating the page to work with a recent change in the Google API. The information displayed is accurate.

To that end, Fox-1 software is simply designed to store key variables in static MRAM (magnetoresistive random access memory) and when a stray particle or other system event causes a reset the IHU simply reboots, reads the latest states from the MRAM, and continues where it left off. In addition, the hardware is designed such that the radio (FM or transponder) will operate as long as there is power in an autonomous state, much like a terrestrial repeater, when the IHU is not working. There is evidence of reset events where stations may have been in QSO at the time of the reset but quite likely never noticed the event because the radio kept working while the IHU rebooted. And Vanderbilt University, our partner with experiments on Fox-1A, Fox-1B, Fox-1C, and Fox-1E provides a wealth of information on COTS components in our (currently) low earth orbits that improves everyone's understanding of what the environment is like and how components are affected, helping understand the choices in components vs. risk vs. cost.

These are basic but important steps, and a very important part of the Fox-1 program in that as AMSAT has always done, we are learning from the designs and the function of our first CubeSats. Failures are undesirable of course, but certainly not expected, because space is a totally nasty environment even for million dollar satellites. Every event whether success or failure, or total head-scratcher event, is part of our process of building satellites and "keeping amateur radio in space".

Eight years is a long time to all of the ham satellite enthusiasts wanting and waiting to be able to work with new satellites, but it is a remarkably short time in the overall process of conceiving, funding, building, and securing launches for satellites by a group of those same hams. Looking back, the seven years that I have been with AMSAT Engineering is “a long time” but in the cycle of each Fox-1 satellite that we build during that period, it was always barely enough!

Amateur radio satellite enthusiasts can celebrate the accomplishments of the Fox-1 program upon the launch of our last two Fox-1 birds, whether you have been around for the duration or are a new member just getting into this exciting part of the hobby.

This effort will continue, with some of the same and many new volunteers, as we proceed on our course of growing our CubeSat capability and continuing the successful deployment of amateur radio satellites. AMSAT has been building satellites to fit whatever space/size is affordably available on a launch vehicle for 49 years, and even further back to the pioneers who would form the Radio Amateur Satellite Corporation when they flew the world’s first private, non-commercial satellite, OSCAR 1. CubeSats are that new affordable size and shape and so we continue our heritage.

We hope you all enjoy the Fox-1 birds made possible by the accomplishments of the volunteers for this fine amateur radio organization, AMSAT!

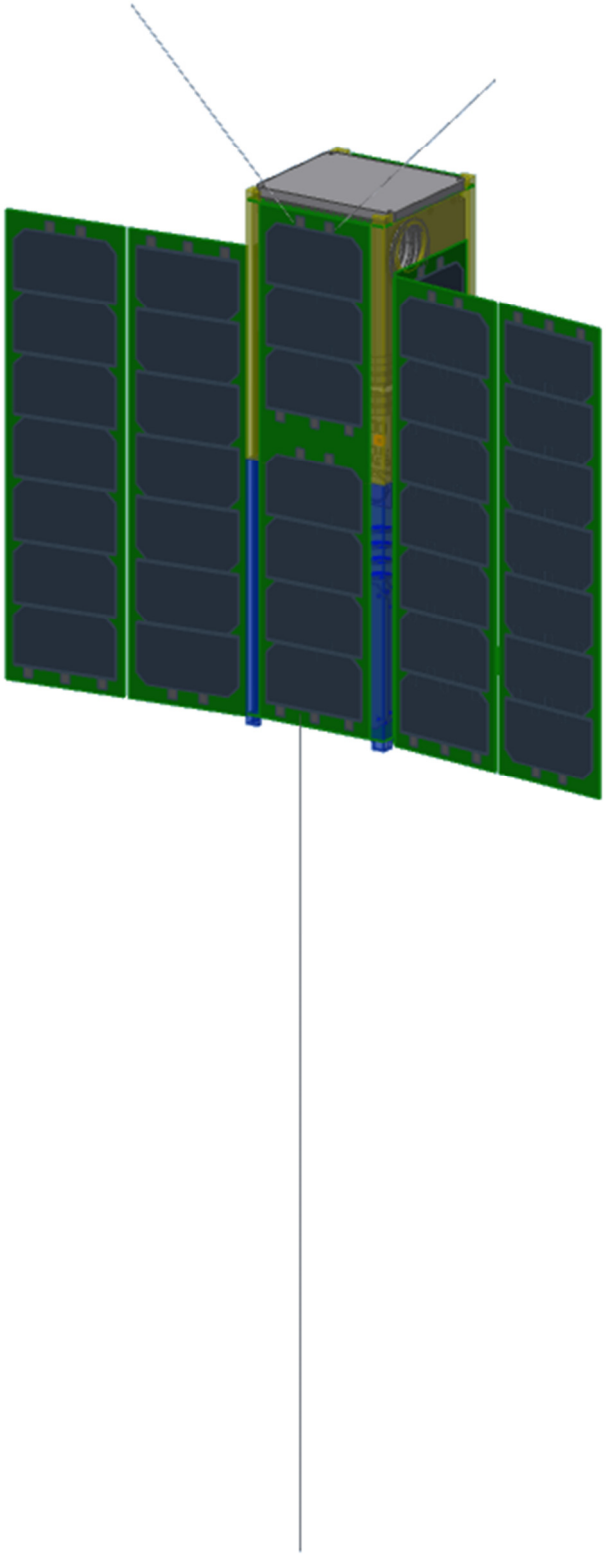

Figure 1 GOLF-TEE deployed panels and antennas

GOLF-TEE Mechanical Design

Bob Davis KF4KSS

AMSAT's next CubeSat is GOLF-TEE, "Greater Orbit, Larger Footprint" – "Technology Evaluation Environment", a 3U CubeSat. It will be 4 kg and 110x110x340.5 mm before the solar panels and antennas deploy. This larger mass and volume over the previous 1U Fox CubeSats allows additional functionality like 3-axis attitude control, deployable solar panels, and additional avionics. AMSAT has teamed with Ragnarok Industries for the 3-axis attitude control, and Vanderbilt University for the experiment.
This paper describes a few mecahnical design features and issues.
Attitude and power sections take up about half the length of the Cubesat.
AMSAT's IHUs, radios, and university experiments use the remaining volume shown below.

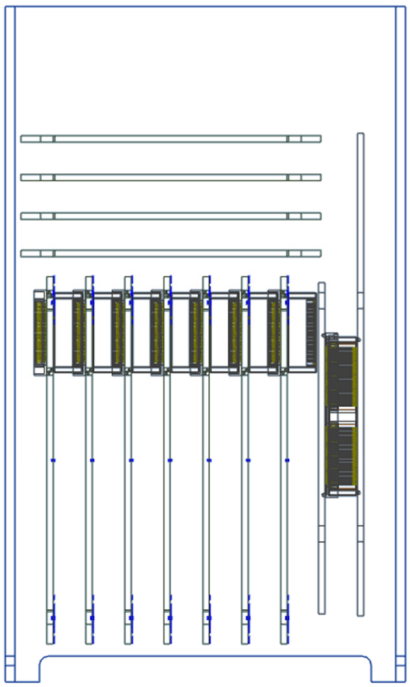

Figure 2 Concept of boards inside AMSAT's half

GOLF-TEE will have an SDR, a radiation tolerance computer (RT-IHU), and have the IHU and linear transponder from RadFxSat-2 as backup.

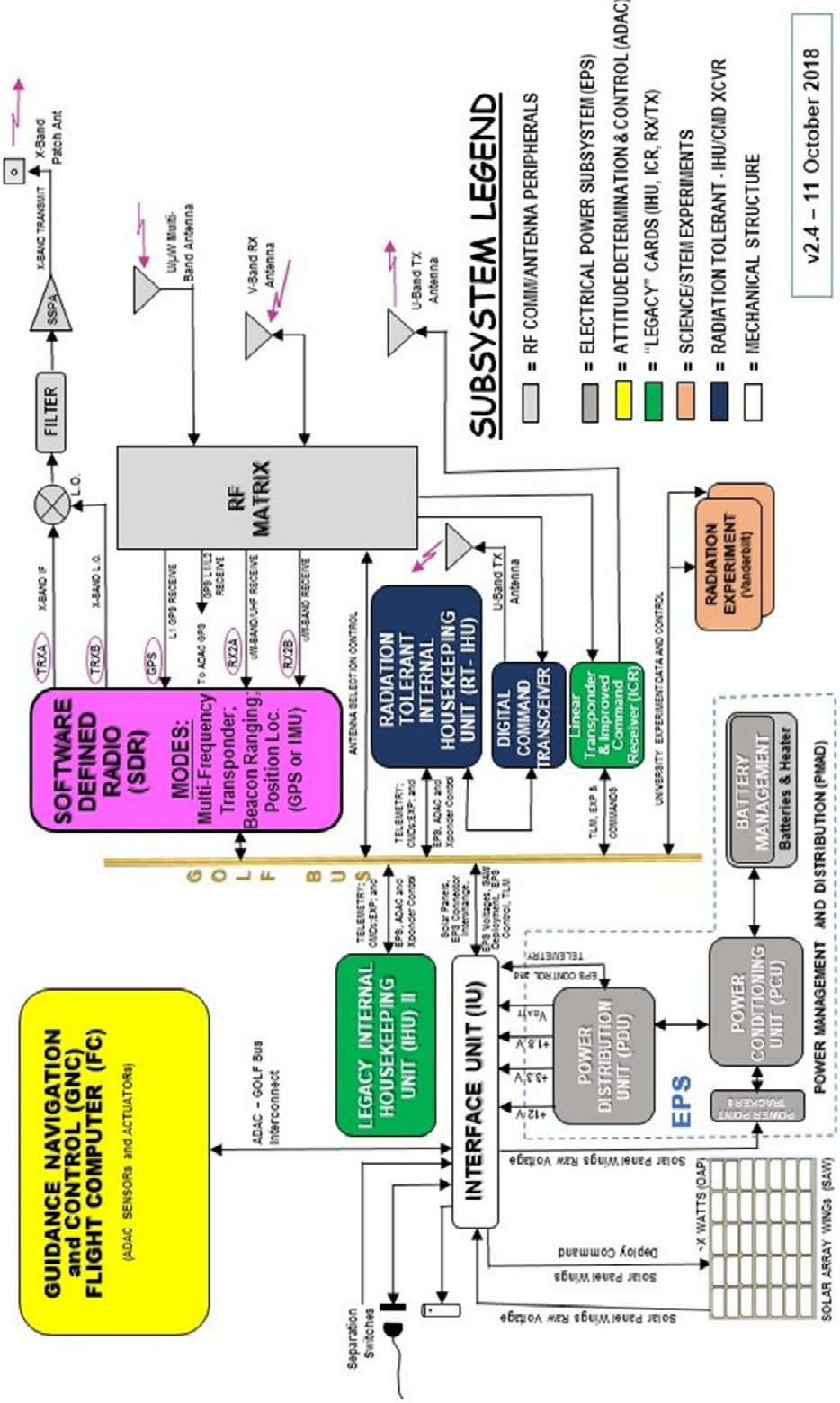

Figure 3 GOLF-TEE Subsystem Block Diagram

Fox's bent sheetmetal frame worked OK. The width between Rails is 100 mm, with a tolerance of +/- 0.1 mm unless specified otherwise for a specific mission or hardware. On the four sides, this tolerance was met in two ways. First, the sheetmetal bender had to properly distance two bends. This is difficult. Second, on assembly, the screw holes were clearance diameter and therefore were insufficient for alignment. The structure widths had to be checked before and after the nuts were torqued. I feared extending the length to 1.5U or even 3U would introduce more complications.

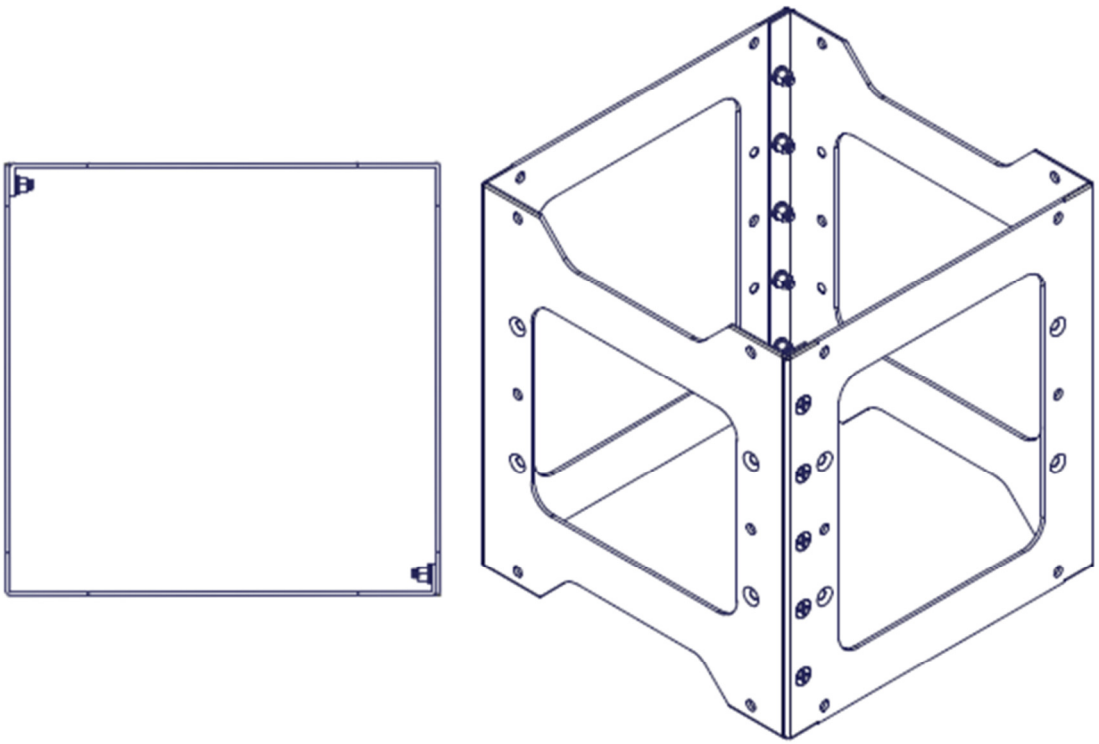

Figure 4 Bent Sheetmetal Structure of Fox

GOLF cross-section is made from thin-walled square aluminum extrusion. This will be cheaper and easier to implement. It's heavier than thinner sheetmetal, but Foxes ended up using lead ballast to approach their mass of 1.33 kg.

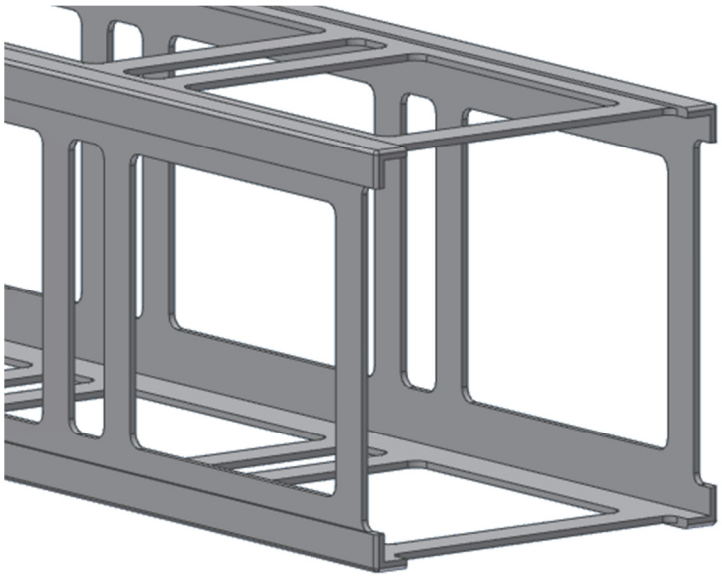

Figure 5 Square Aluminum Tube of GOLF

The exterior of a 4x4 inch tube has tolerances from the factory that are good enough to reliably mill all four sides down to 100.0 x 100.0 +/-0.1 mm. This extra step burdens our machinist, but then these tolerances are forever resolved. The 340.5mm overall length will be split, so that the two major "halves" can be independently assembled and tested, then brought together. So the joint will also have to be checked for proper alignment.

Similar to Fox, GOLF boards will stack, and will have limited thermal conduction to the structure. The exact order of boards has not been decided, but we have identified all boards and some details of which should be neighbors within stacks.

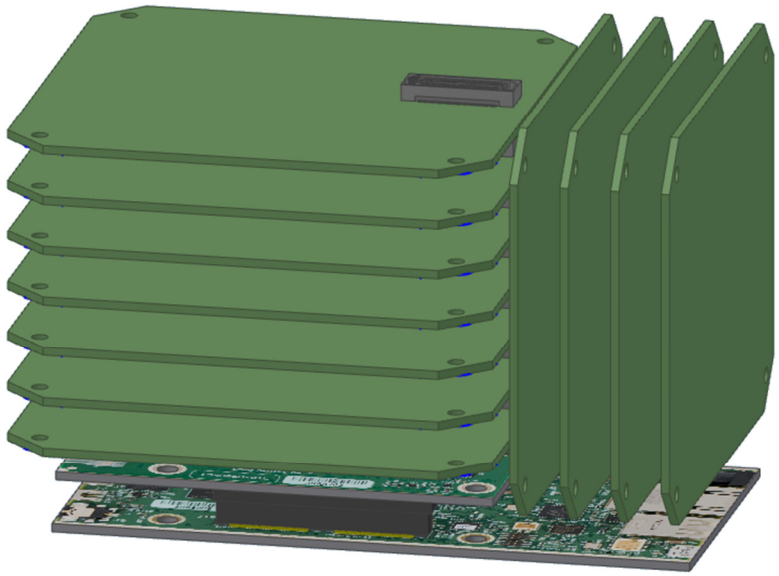

Figure 6 Circuit Board Stacks

The solar panels stow, and have 2 hinges for each “wing”. They stow with solar cells outward. They will be restrained similar to Fox antennas, with fishing line and a melt resistor. There are no details yet for the hinges or restraints. A key focus of the prototype will include stiffness of the panels. Since they are “poorly supported” at only a few points, their natural frequency in a “drum mode” will be low.

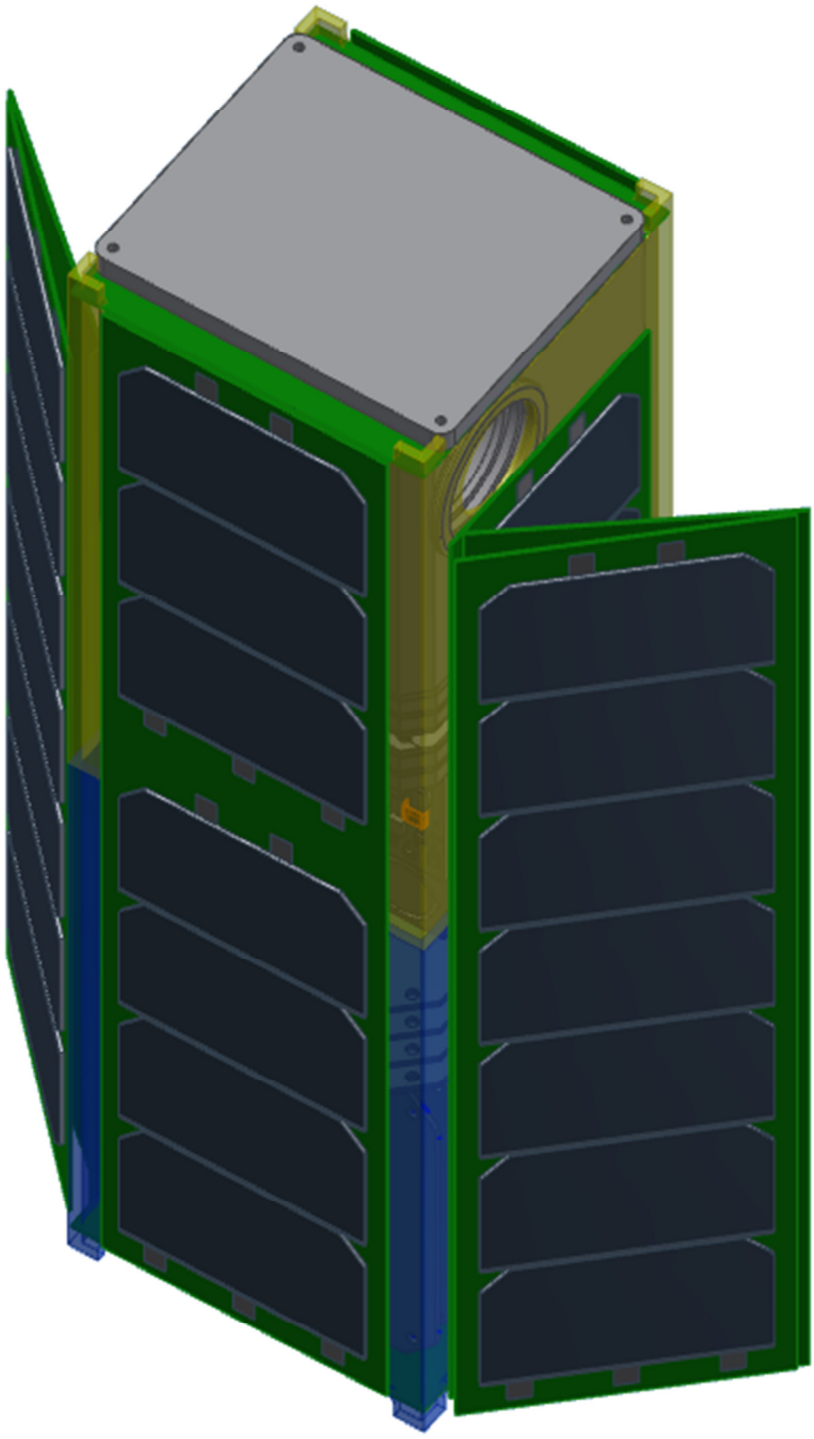

Figure 7 Solar Panel hinges moving toward stowed

The power budget has been estimated, based on a couple “extremes” of potential orbits (max eclipse, no eclipse, and somewhere in between). The attitude is likely to remain earth-pointing, and simply rotating the cells toward the sun. This may appear to be passive gravity gradient orientation, but in fact without a boom mass this ends up having to be an active attitude mode.

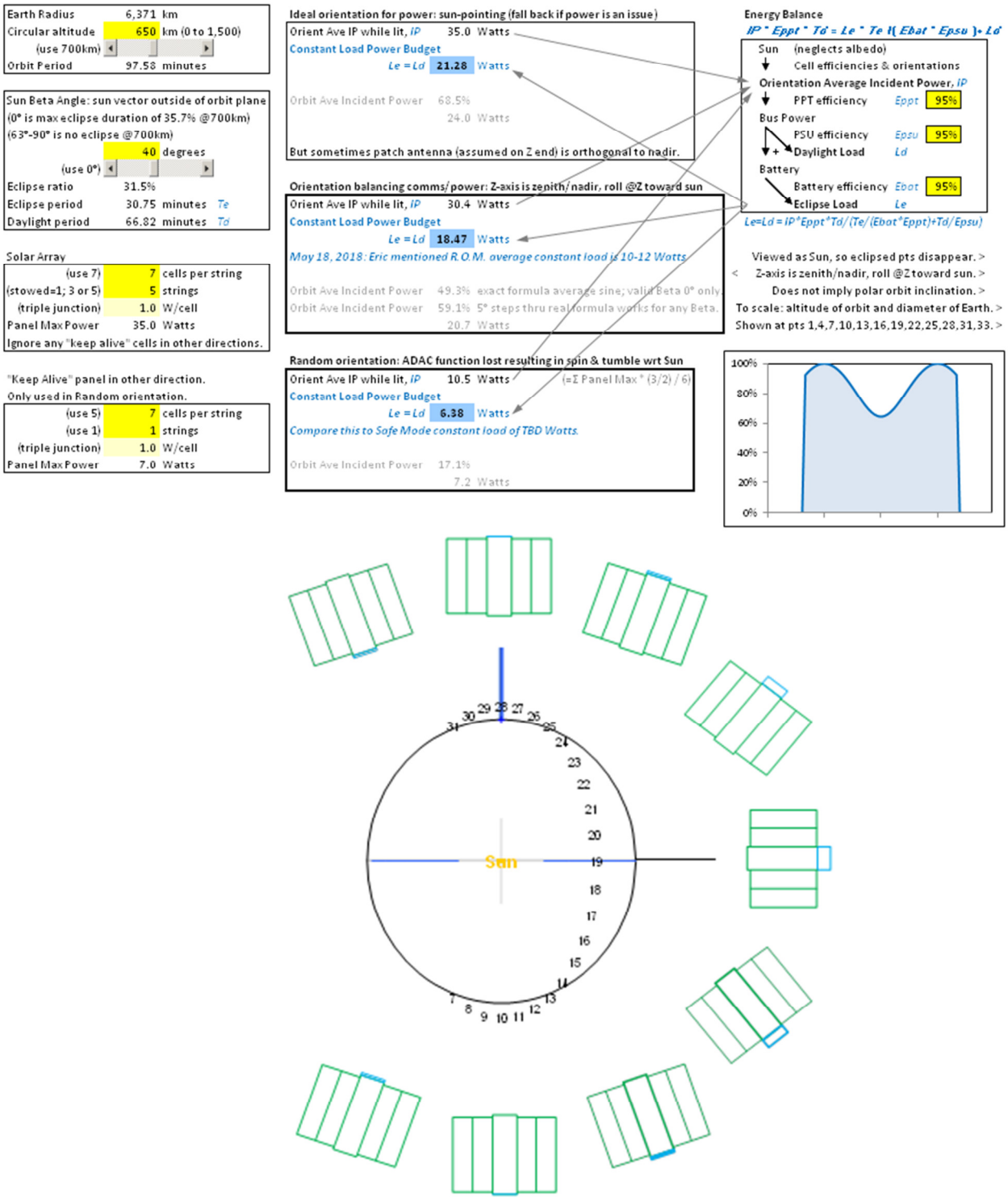
Earth Radius 6,371 km
Circular altitude 650 km (0 to 1,500)
(use 700km)
Orbit Period 97.58 minutes
Sun Beta Angle: sun vector outside of orbit plane
(0° is max eclipse duration of 35.7% @700km)
(63°-90° is no eclipse @700km)
40 degrees
(use 0°)
Eclipse ratio 31.5%
Eclipse period 30.75 minutes Te
Daylight period 66.82 minutes Td
Solar Array
(use 7) 7 cells per string
(stowed=1; 3 or 5) 5 strings
(triple junction) 1.0 W/cell
Panel Max Power 35.0 Watts
Ignore any "keep alive" cells in other directions.
"Keep Alive" panel in other direction.
Only used in Random orientation.
(use 5) 7 cells per string
(use 1) 1 strings
(triple junction) 1.0 W/cell
Panel Max Power 7.0 Watts
Ideal orientation for power: sun-pointing (fall back if power is an issue)
Orient Ave IP while lit, IP 35.0 Watts
Constant Load Power Budget
Le = Ld 21.28 Watts
Orbit Ave Incident Power 68.5%
24.0 Watts
But sometimes patch antenna (assumed on Z end) is orthogonal to nadir.
Orientation balancing comms/ power: Z-axis is zenith/ nadir, roll @Z toward sun
Orient Ave IP while lit, IP 30.4 Watts
Constant Load Power Budget
Le = Ld 18.47 Watts
May 18, 2018: Eric mentioned R.O.M. average constant load is 10-12 Watts
Orbit Ave Incident Power 49.3% exact formula average sine; valid Beta 0° only
Orbit Ave Incident Power 59.1% 5° steps thru real formula works for any Beta.
20.7 Watts
Random orientation: ADAC function lost resulting in spin & tumble wrt Sun
Orient Ave IP while lit, IP 10.5 Watts (=Σ Panel Max * (3/2) / 6)
Constant Load Power Budget
Le = Ld 6.38 Watts
Compare this to Safe Mode constant load of TBD Watts.
Orbit Ave Incident Power 17.1%
7.2 Watts
Energy Balance
IP * Eppt * Td = Le * Te +(Ebat * Epsu)• Ld
Sun (neglects albedo)
Cell efficiencies & orientations
Orientation Average Incident Power, IP
PPT efficiency Eppt 95%
Bus Power
PSU efficiency Epsu 95%
+ Daylight Load Ld
Battery
Battery efficiency Ebat 95%
Eclipse Load Le
Le=Ld = IP*Eppt*Td/(Te/(Ebat*Eppt)+Td/Epsu)
Viewed as Sun, so eclipsed pts disappear. >
< Z-axis is zenith/nadir, roll @Z toward sun. >
Does not imply polar orbit inclination. >
To scale: altitude of orbit and diameter of Earth. >
Shown at pts 1,4,7,10,13,16,19,22,25,28,31,33. >
100%
80%
60%
40%
20%
0%
Sun

Figure 8 Power Budget estimation using sample orbit

The “Greater Orbit, Larger Footprint” does mean that we are aiming for a higher altitude (perigee/apogee). Now, the max 25 year orbit lifetime also must be considered. The cross-sectional area of GOLF varies with attitude. If the “end” with smallest cross-section is presented to the orbit velocity vector, then the orbit lifetime is a maximum. If the fully deployed solar panels are presented to the orbit velocity vector, then the orbit lifetime is a minimum. This will be examined more closely later to verify compliance.

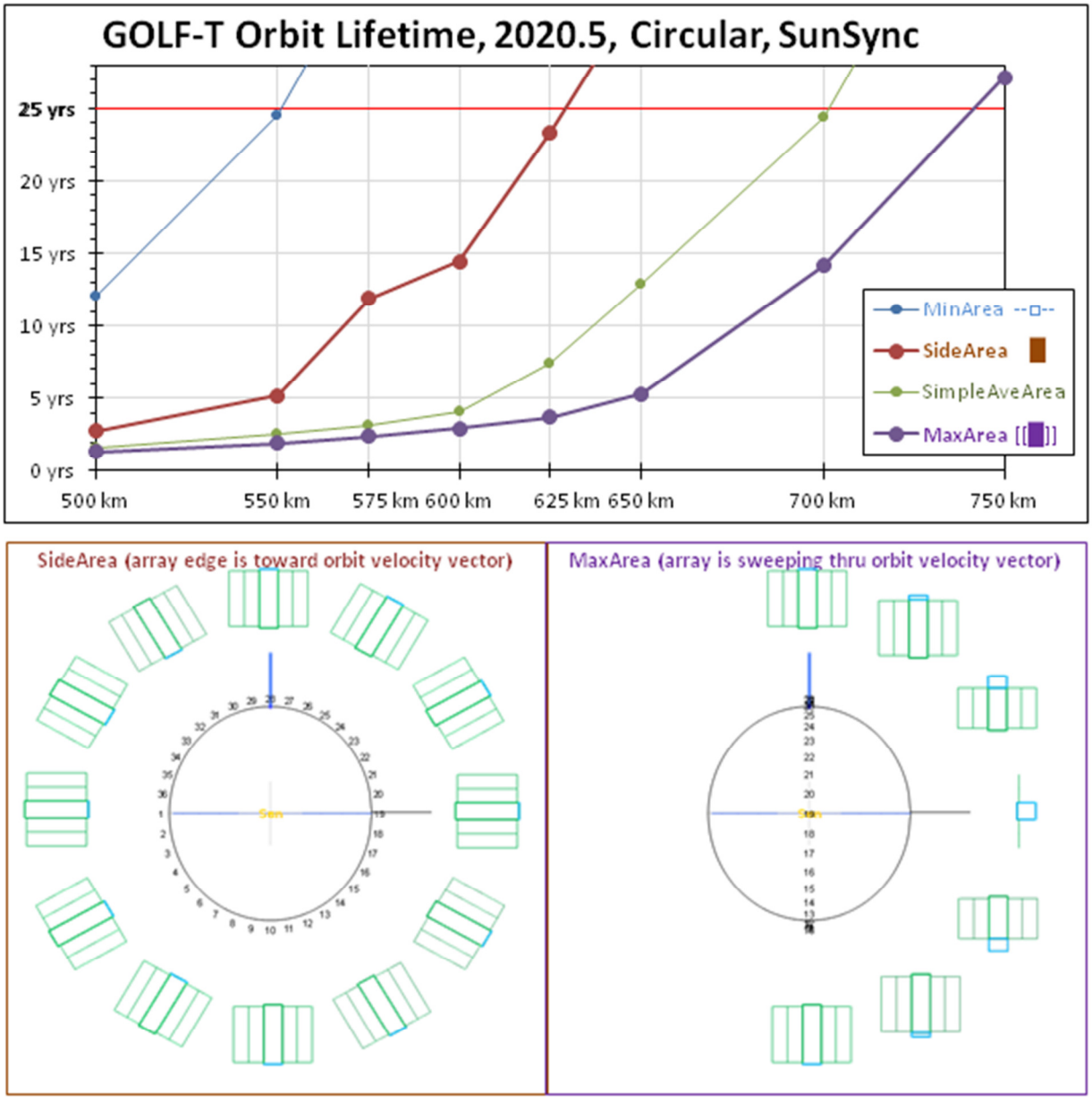

Figure 9 Study of cross-sectional area's effect on orbit lifetime

Near-term, the preliminary mechanical design must be completed. This includes interfaces between major parts like structure, boards, panels, and large components. An effort will soon start to detail the solar panel hinges and restraints. Then a mockup will be examined for natural frequency of the solar panels, and also used to validate a simple Finite Element Model. We have a couple volunteers to tackle the mockup, the FEA, and prototype vibration testing.

We are also looking into how to thermally analyze parts of the assembly like heatsinks, and how to analyze the overall model in orbit orientations. We have a couple volunteers who are preparing to analyze parts. We are looking for the proper solution to analyze the overall model.

Some of the Fox thermal design intent can be “reused” on GOLF. But GOLF has two factors making the thermal design important to not overlook: power density and orbit orientation. With deployed solar panels, we can generate more power on GOLF than Fox. With more volume, we can have more components dissipating power. Considering dissipated power vs radiating exterior area, GOLF is denser and therefore would be expected to be hotter. Also, Fox had an “averaging” effect from spinning around a magnet (which itself caused tumbling). However, GOLF has in general a hot side corresponding to the deployed solar panels. I am not a thermal engineer, but I recognize that all of these factors cause GOLF thermal design to be more complicated than Fox.

More volunteers are always welcome!

Digital Voice on Amateur Satellites
Experiences with LilacSat-OSCAR 90

Paul Stoetzer, N8HM
n8hm@amsat.org

While narrowband digital text modes like PSK31, JT65, and FT8 have swept HF, and digital voice modes such as DMR, D-STAR, and C4FM have proven quite popular for terrestrial VHF and UHF repeaters, digital voice modes have not come into common use either on HF or amateur satellites. This paper will discuss ideas for the future use of digital voice modes on amateur satellites by exploring the author's experiences with LilacSat-OSCAR 90, an amateur satellite featuring a transponder with an FM uplink and a Codec2 downlink.

About LilacSat-OSCAR 90 (LO-90)

LilacSat-1 is a 3U CubeSat that was constructed at the Harbin Institute of Technology in Harbin, China as part of the QB50 mission to study the lower thermosphere. The satellite was deployed from the International Space Station on May 25, 2017. The satellite's main payload is an ion and neutral particle mass spectrometer developed by the University of London[1]. The satellite's amateur radio capabilities include a transponder with a 145.985 MHz FM uplink and a 9600 bps BPSK downlink at 436.510 MHz. Downlink power is 200 or 500 mW. Amateur operators may also operate the satellite's onboard camera by sending a 1000 bps AFSK AX.25 UI command.[2]The downlink accommodates telemetry, camera, and voice in the same stream. A 7 byte 1300 bps Codec2 frame encoding 40 ms of the FM uplink audio is included in each 120 byte packet. The remaining space in each packet is used for telemetry and camera data (sent in JPEG format). More details about the downlink format can be found at https://destevez.net/2017/05/low-latency-decoder-for-lilacsat-1/.

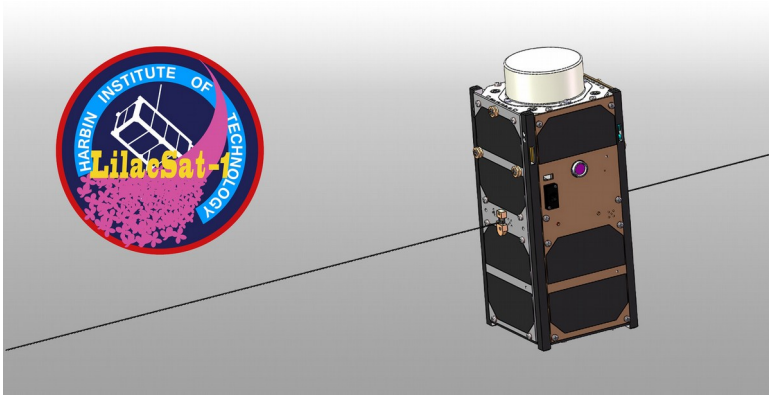

Figure 1 – LilacSat-1

1 "LilacSat-1 CubeSat deployed from ISS." AMSAT-UK. https://amsat-uk.org/2017/05/19/lilacsat-1-cubesat-iss/. Accessed October 14, 2018.
2 "LilacSat-1 Radio Info." LilacSat. http://lilacsat.hit.edu.cn/wp/?page_id=594. Accessed October 14, 2018.

LilacSat-1 was designated LilacSat-OSCAR 90 or LO-90 by AMSAT on June 20, 2017. Unfortunately, as it was deployed from the ISS, its remaining lifetime is limited. As of this writing, LO-90 is in an orbit of 343 km x 340 km with an inclination of 51.6 degrees. Calculations by Mike Rupprecht, DK3WN, predict a decay date of February 13, 2019.[3]

About Codec2

Most amateur radio digital voice modes utilize a proprietary codec from a family known as AMBE (Advanced Multiband Excitation). DMR, D-STAR, and C4FM all utilize versions of AMBE. Codec2, on the other hand, is a fully open source speech codec designed for low-bitrate digital voice communications. Bitrates of between 700 and 3200 bps are available. Most amateur radio use of Codec2 is in the form of FreeDV, a digital voice software package utilizing the Codec2 voice codec, FDMDV modem, and forward-error correction. FreeDV allows amateur radio operators to easily use digital voice on standard HF SSB transceivers using the same equipment used for soundcard digital modes, such as FT8 and PSK31, on HF (though an additional soundcard is generally necessary). FreeDV is robust – the 700D version outperforms SSB in poor conditions.[4]

Operating through LO-90

Utilizing LO-90's FM to Codec2 transponder requires nothing more than a 2 meter FM transceiver (a 5 watt HT is sufficient), a modern computer (most laptop or desktop computers from the last decade should suffice), an adequate antenna (a handheld Arrow Antenna works well), and a software-defined radio receiver (a $22 RTL-SDR.com USB dongle is sufficient, a FUNcube Dongle or AirSpy will provide better results). The challenge in receiving the downlink is on the software side. The available decoders are GNU Radio flowgraphs available only for Linux systems. Although it may technically be possible to compile these decoders for MacOS or Windows systems, it would require significant effort. Fortunately, M6SIG produced a live ISO image containing the necessary tools that can be downloaded and imaged to a USB stick.[5] This image is based on Ubuntu and will boot and run on most modern systems. The other option is to install these decoders on an existing Linux system. However, successful installation does require moderate Linux experience. Installation steps vary by distribution.

The decoders provided by the Harbin Institute of Technology, gr-lilacsat, work well but have a significant handicap. These decoders wait until an entire frame is received before passing the voice data to the Codec2 decoder. This introduces 200 ms of latency. Daniel Estévez, EA4GPZ, includes a low-latency decoder that passes the voice data to the Codec2 decoder as soon as it is received in his gr-satellites package.[6]

Once the software is up and running, the operating experience is similar to any FM satellite. FM transmissions with a 67.0 Hz tone are encoded in the satellite, then transmitted, and received and decoded by the software. The audio produced is clearly digital, though with good signals, it can be quite pleasant.

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3 "Decay." DK3WN Satblog. http://www.dk3wn.info/p/?page_id=43437. Accessed October 14, 2018.

4 "Codec 2" Rowetel. https://www.rowetel.com/?page_id=452. Accessed October 14, 2018.

5 Links to the various software and articles about the technical characteristics of the LO-90 downlink are available at http://lilacsat.hit.edu.cn/wp/?page_id=594. However, M6SIG's live image is no longer available at that link. Please email the author for a link if you are interested in trying the live image.

6 "Low Latency Decoder for LilacSat-1." https://destevez.net/2017/05/low-latency-decoder-for-lilacsat-1/. Accessed October 14, 2018.

Below are some screenshots of various setups used by several different stations:

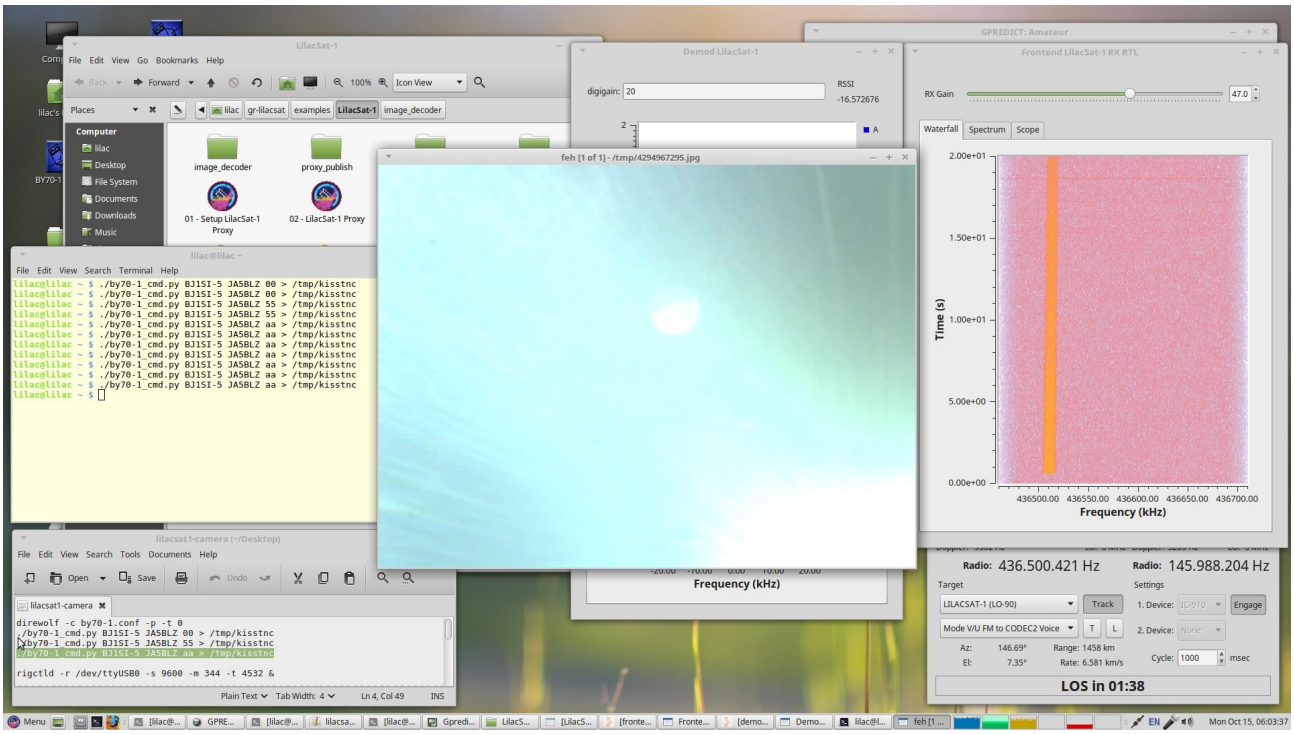

Figure 2 – A screenshot from JA5BLZ using the gr-lilacsat tools and commanding the camera on Linux Mint.

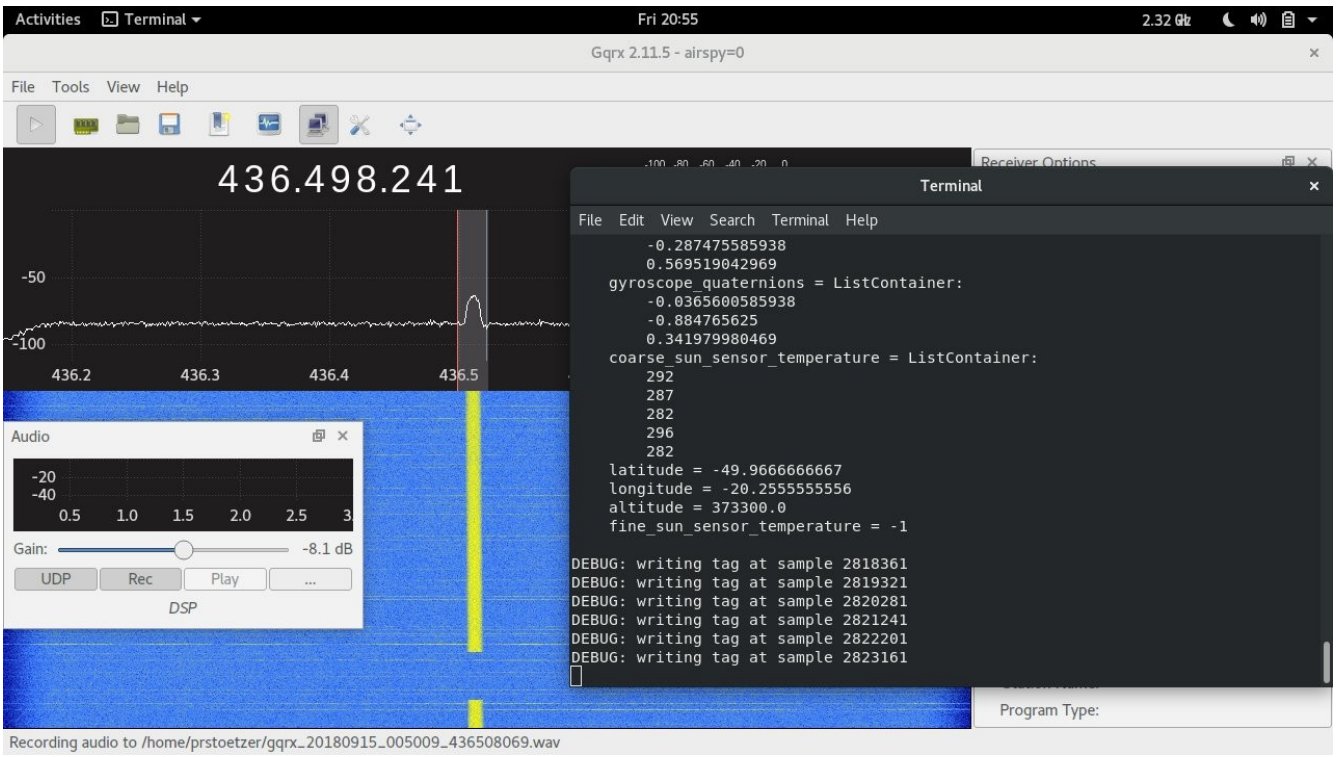

Figure 3 – A screenshot of the author operating through LO-90, using EA4GPZ's gr-satellites decoder on Fedora 28.

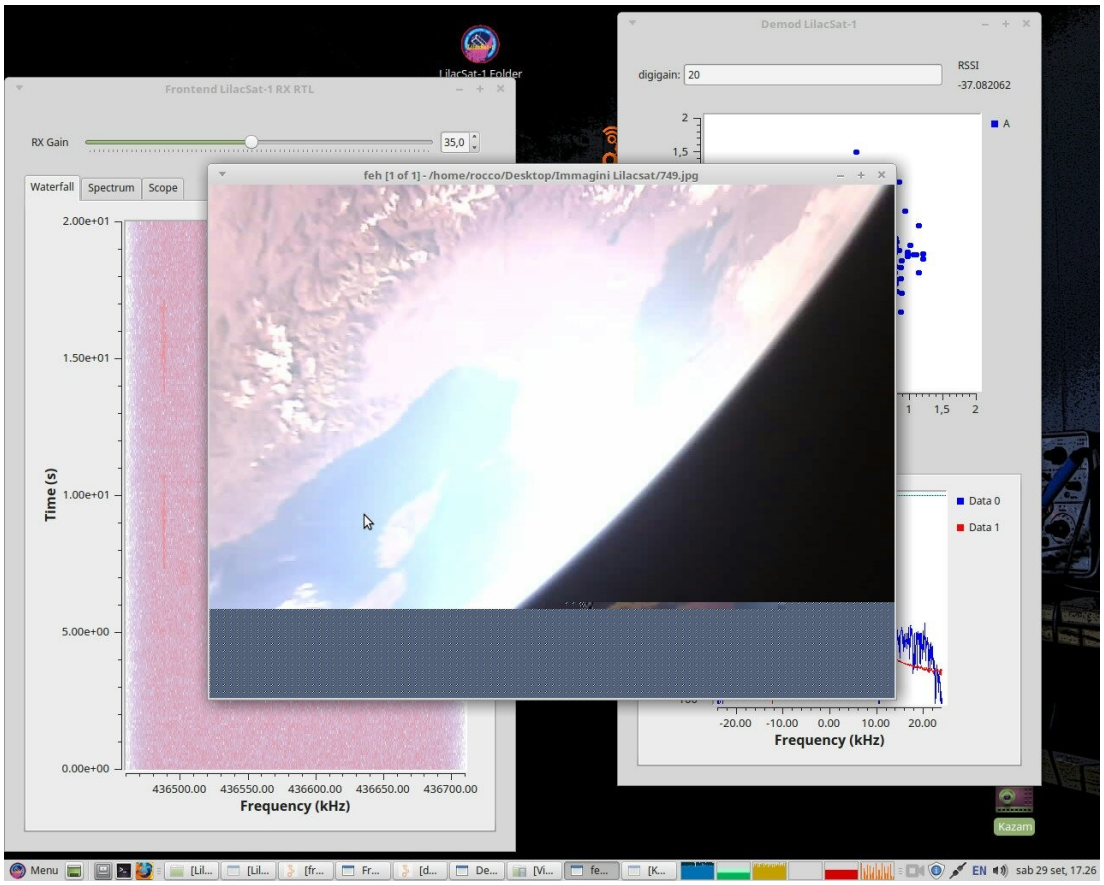

Figure 4 – IK8XLD receives most of an excellent Earth image with gr-lilacsat

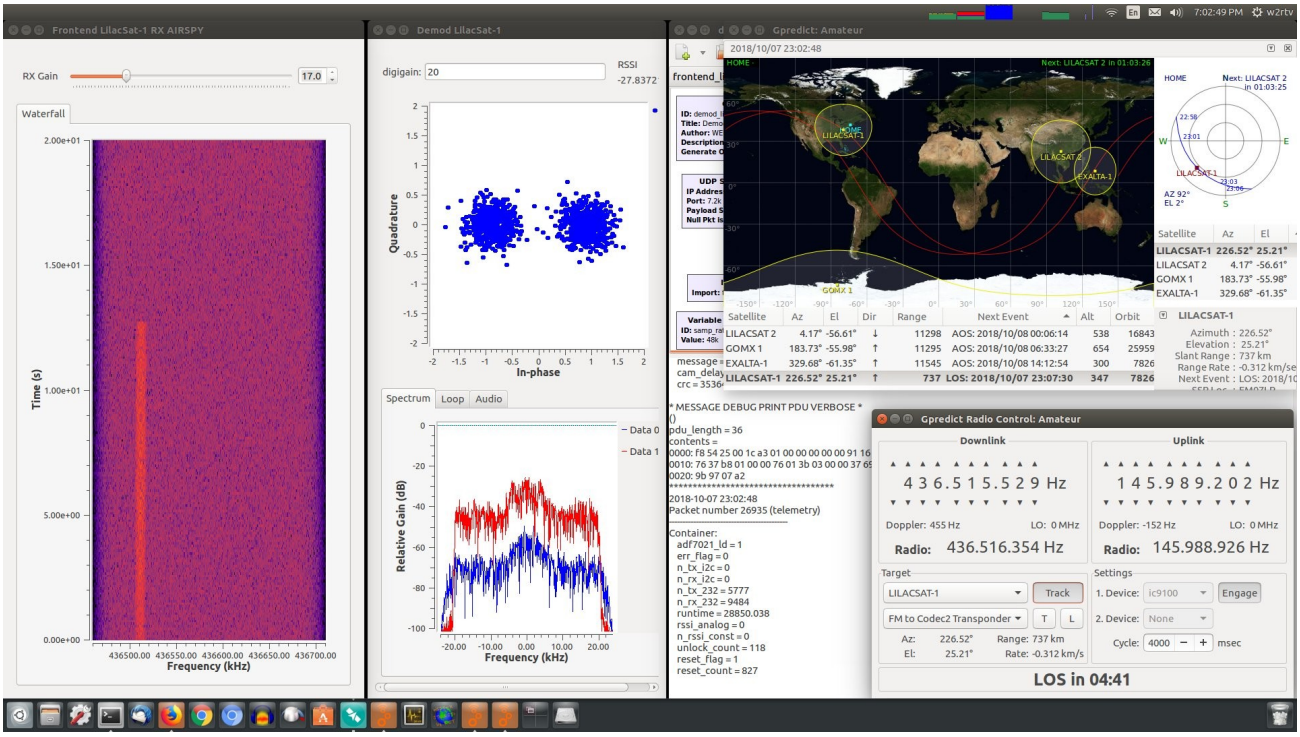

Figure 5 – W2RTV's screen during a QSO with K4KDR

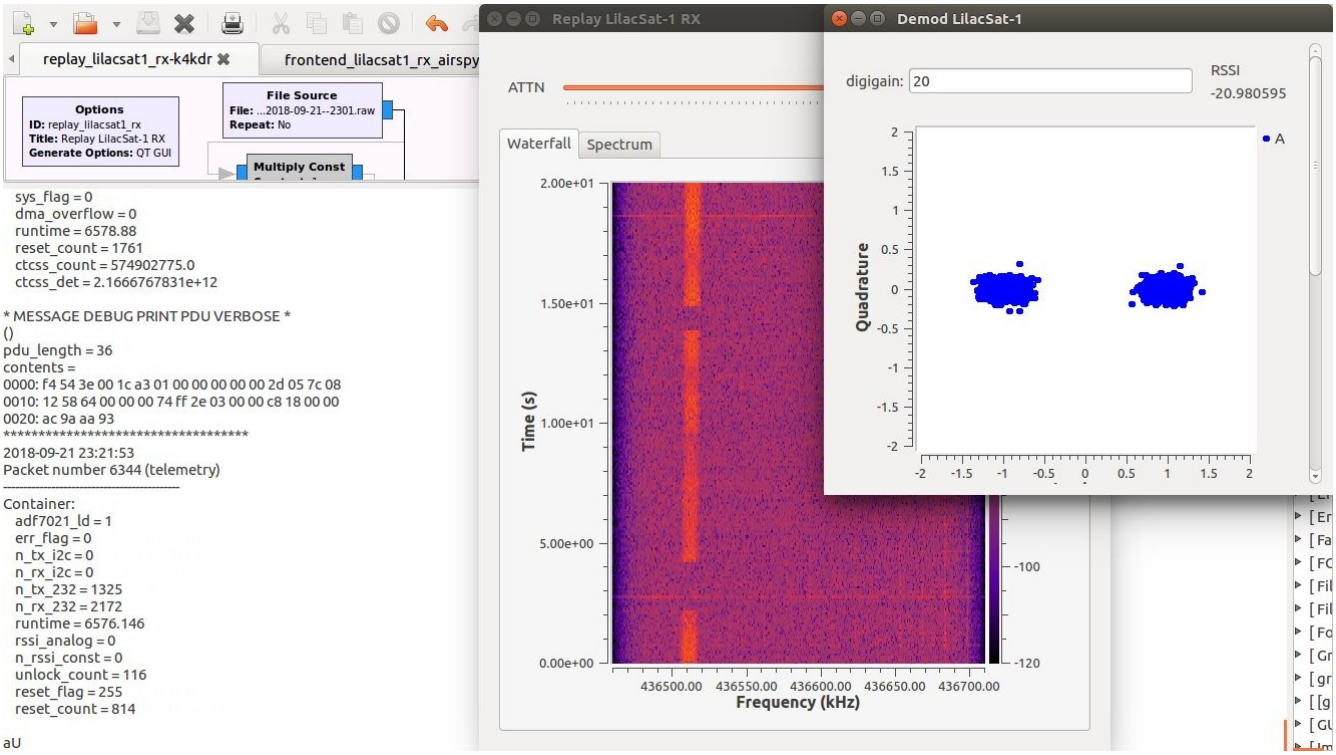

Figure 6 – K4KDR's screen during a QSO with the author

Unfortunately, LO-90 has not seen widespread use, likely due to a general unfamiliarity with Linux among most amateur radio operators. Only 10 stations in North America are known to have completed a QSO via LO-90 as of this writing.

K0FFY
K4KDR
KB1PVH
KC4LE
KE8FZT
N6RFM
N8HM
NB3T
VE7CEW
W2RTV

Figure 7 – Stations in North America known to have completed a QSO via LO-90

The Author's Portable LO-90 Station

I currently live in an apartment building in Southwest Washington, DC. This requires me to operate fully portable and often to move around the building during a pass. This requires a completely portable solution that can be used and carried around during the pass. In August 2018, I acquired a GPD Win. This is a handheld computer designed as a portable computer for playing PC games on the go (there is an integrated game controller pad). This computer features an Intel Atom X7-Z8750 processor capable of operating at up to 2.56 GHz, 4 GB of RAM, and 64 GB of eMMC storage. While these are low-end specifications, it is plenty of power for narrowband SDR applications. Immediately upon receipt, I wiped the pre-installed version of Windows 10 Home in favor of Linux. While my preferred distribution is Arch Linux, the GPD Win contains some odd hardware quirks and I could not get it working, so I installed my second-favorite distribution, Fedora. All hardware worked out of the box on Fedora with just a minor tweak required to get the system's WiFi working. After installing Linux, my first goal was to get this working for use decoding the LO-90 downlink. Although it took the better part of a day, I was finally able to get EA4GPZ's gr-satellites up and running on the machine (attaching an external keyboard, monitor, and mouse would have sped up the process). After waiting for the next pass, I was able to confirm that everything worked as intended. I was now able to use LO-90 with a very small, portable setup as seen below.

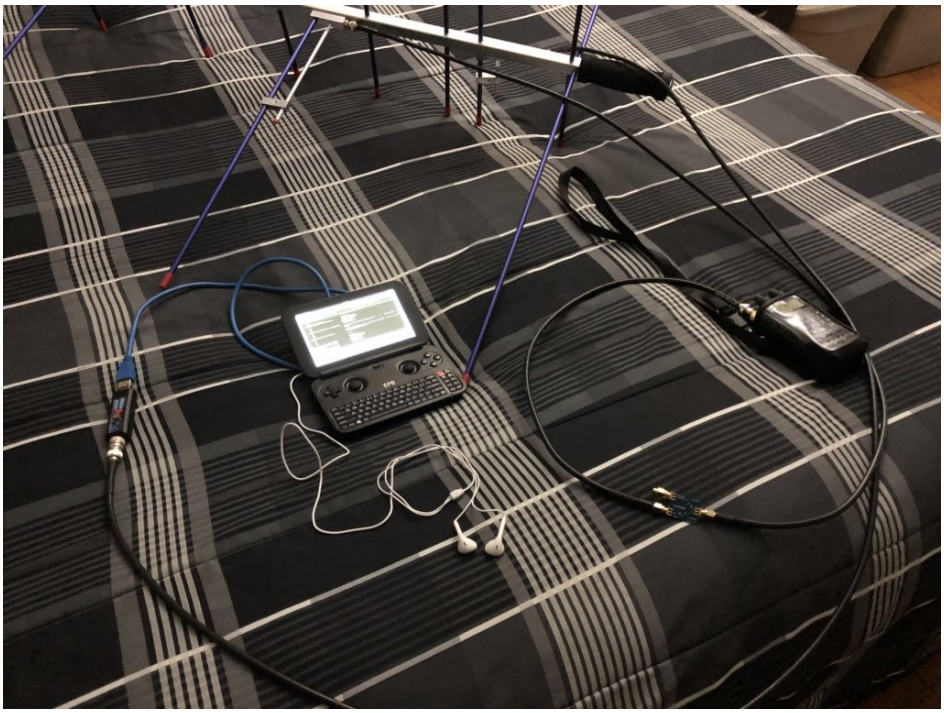

Figure 8 – The "World's Smallest LO-90 Station" - A GPD Win handheld PC, a FUNcube Dongle Pro+, an Alinco DJ-G7T HT, and an Arrow Antenna.

In order to carry the equipment around, I use a Connect-A-Desk. This product is designed as a harness for a laptop computer. In practice, I find it difficult to use with a full-size laptop, especially when also carrying an Arrow Antenna. The GPD Win, on the other hand, is relatively convenient to use while being carried around this way.

Figure 9 – The author's Connect-A-Desk with the GPD Win and an AirSpy Mini

Unfortunately, after just a few passes, I broke the USB connector off my FUNcube Dongle Pro+ while carrying it around dangling by the USB cable and coax. I replaced it with an AirSpy Mini. I also tested a $22 RTL-SDR.com dongle with adequate results.

One important note when operating this way – the third harmonic of the 2 meter transmitter significantly harms recption while transmitting. This can be cured with a diplexer or low-pass filter on the output of the 2 meter transmitter. Depending on the SDR, you may also encounter front end overload, requiring a filter on the input of the SDR.

Although this is not exactly a "grab and go" setup like an HT and Arrow Antenna for an FM satellite or even two FT-817s and an Arrow for linear transponders, it is a very portable setup and a good proof of concept for what is possible to do while portable.

Future Satellites Utilizing Codec2

Taurus-1, a 2U CubeSat developed by the AeroSpace System Engineering Research Institute of Shanghai plans to incorporate an VHF/UHF FM-to-Codec2 digital transponder similar to LO-90. According to the IARU coordination request, a February 2018 launch was planned.[7] However, no further information on the status of this project is available at the time of this writing.

7 Taurus-1 Frequency Coordination. The International Amateur Radio Union. http://www.amsatuk.me.uk/iaru/finished_detail.php?serialnum=568 Accessed October 14, 2018.

Conclusion - The Future of Digital Voice on Amateur Satellites

As of this writing, LO-90 is the only satellite to have successfully demonstrated a digital voice mode in orbit. D-STAR ONE from German Orbital Systems was launched in 2018 but was not successful. Two other satellites, Oufti-1 and TableSat-Aurora, also included D-STAR systems, but were not successful. D-STAR was successfully used through the AO-27 satellite in 2007, but this was simply using the satellite as a bent-pipe. A few attempts to make a FreeDV QSO on FO-29 have been also been made. German Orbital Systems does plan another attempt at a D-STAR satellite and, as noted above, there is potentially another FM-to-Codec2 satellite in the works, but what about some other ideas for future projects?

Digital voice offers several advantages. The first major advantage is bandwidth. For example, AO-92 and Fox-1Cliff, the two AMSAT Fox-1 satellites with a camera, can not transmit images and voice at the same time. When the camera is operating, the transponder does not. In nearly the same bandwidth, LO-90 transmits telemetry, camera data, and voice data simultaneously. Activating the camera does not require the transponder to be deactivated.

Expanding upon this concept, perhaps a future satellite could include multiple channels of digital voice. LO-90 uses 1300 bps Codec2. Utilizing 700 bps Codec2, perhaps two channels of voice could operate simultaneously with the camera and telemetry data. 700 bps Codec2 would also be ideal for amateur CubeSats in HEO where a low SNR is expected. In LEO, a satellite with a high date rate microwave downlink could have many channels of voice and other data, perhaps including store-and-forward messaging and real-time text messaging.

The main lesson that can be learned from LO-90 is that in order for a system like this to be successful, multi-platform software support is crucial. Most amateur radio operators are not Linux enthusiasts and are not interested in booting to a different operating system to operate through a satellite. Any future digital voice satellite must have easy-to-use ground station software for Windows, MacOS, and Linux to be fully successful.

Figure 10 – LO-90 QSL Card

Designing the Fox-1E PSK Modulator and FoxTelem demodulator

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Keywords: BPSK Modulation, BPSK Demodulation, FoxTelem, Costas Loop, Gardner Carrier Recovery, Java

Abstract. Unlike the FM Fox-1 spacecraft, Fox-1E will transmit telemetry and science data to the ground using Phase Shift Keying (PSK). There is a long history of PSK within AMSAT and a wealth of knowledge. This paper discusses the design of a PSK generator with the LTC5599 quadrature modulator. It then provides an update on FoxTelem and the capabilities needed to recover the carrier with a Costas Loop and cleanly demodulate PSK in software.

Part 1: PSK Modulator

With the decision to use PSK on Fox-1E, we wanted to design a modulator that would work seamlessly with the existing IHU. PSK changes the phase of the carrier to convey information. In its simplest form it changes the phase by 180 degrees or pi radians and is called Binary Phase Shift Keying or BPSK. The diagram below from the ARRL Handbook (ARRL, 2017) shows that this is conceptually simple. We apply the data signal to the local oscillator port of a mixer and use it to chop the RF carrier from one phase to another.

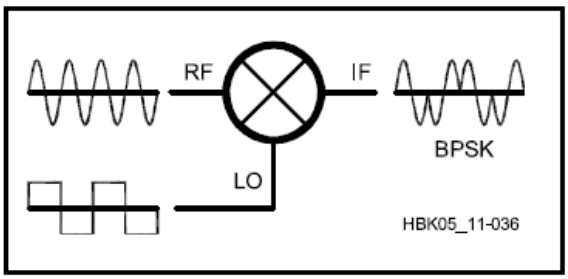

Figure 1 – BPSK Modulation, From the Section 10 of the ARRL Handbook

Balanced Modulator

BPSK is a double sideband suppressed carrier modulation and we can produce it from a simple balanced modulator (Miller, 1991). A simple test uses a balanced modulator such as the SA602 from the junk box.

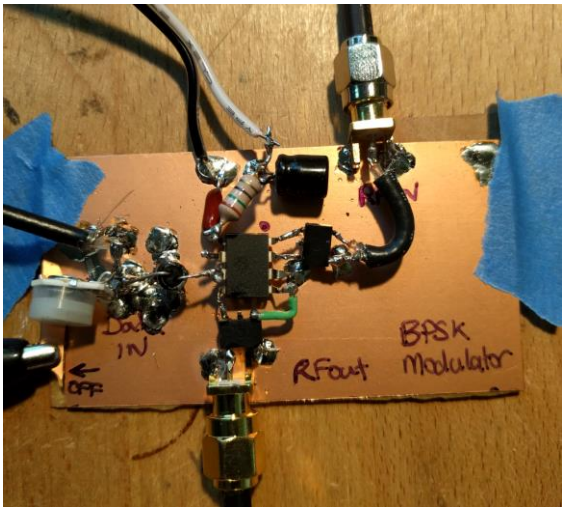

Figure 2 – A dead-bug SA602 prototype, one of many designs built

The Local Oscillator was driven with a 200mV p-p data signal. The circuit used 1:4 and 4:1 baluns to give balanced input/output and a better match to the 1.5k impedance that the SA602 has. The test signal was produced by an Arduino emulating the spacecrafts Internal Housekeeping Unit (IHU) because an IHU was not available.

This balanced modulator prototype worked well but gives a very wide signal as shown in the plot below from HDSDR. This signal is wide because a square wave has a very wide bandwidth.

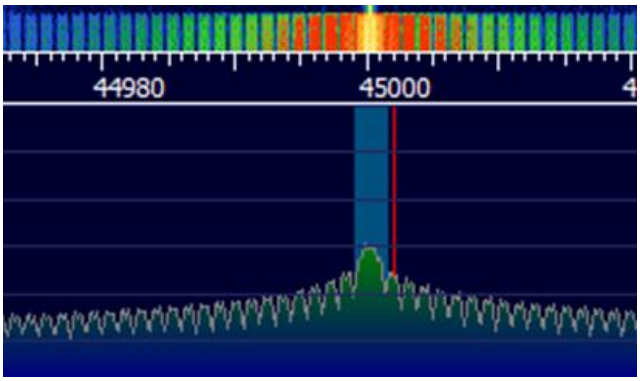

Figure 3 – Spectrum of BPSK signal with unfiltered bits

Filtering the Bits

The wide signal is addressed by filtering the input signal.

As a test an RC filter with a corner frequency of 600Hz was added to the prototype. It rolls off at just 6dB per octave. It is a 270ohm resistor and a 1uF capacitor.

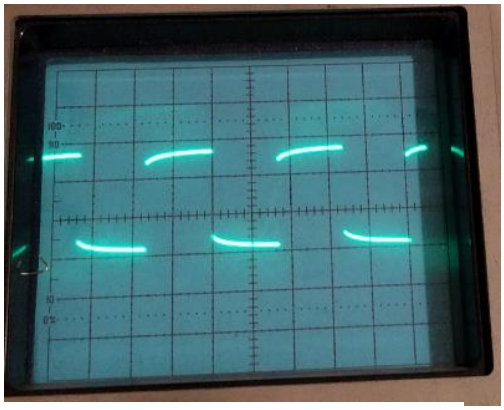

Figure 4 – Filtered bits

The wave form is only slightly filtered as a result, so it looks like the image in the oscilloscope to the right.

The filtered bit stream was applied to the mixer and the output spectrum is shown below. All other settings are the same, including making sure the drive level was adjusted to compensate for the filter loss. This demonstrates that only a gentle amount of filtering is needed to dramatically improve the bandwidth.

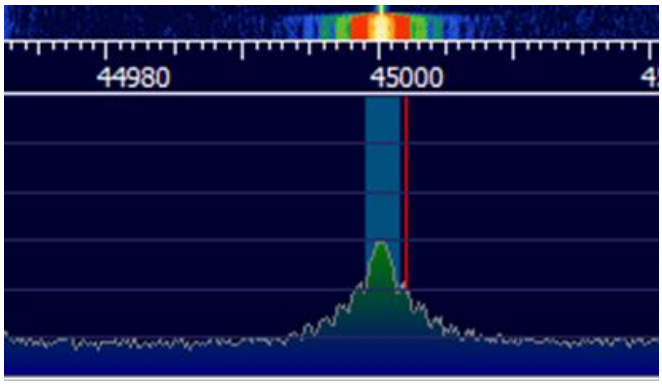

Figure 5 – Spectrum of BPSK Signal with Filtered Bits

The right filter does more than just narrow the bandwidth. Any filter introduces a delay so that one bit smears into the next (Miller, 1991). This causes inter symbol interference (ISI). Filter delay can not be avoided, but the best filter maximizes the amplitude in the middle of the bit and has zero output at the center of all other bits. This can be achieved with a raised cosine filter.

We followed the normal approach of using a root raised cosine filter for the transmitter and another root raised cosine filter for the demodulator. This gives a raised cosine response for the end to end channel. It was implemented as a short Finite Impulse Response (FIR) filter in the IHU on the spacecraft.

Quadrature (IQ) Modulator

To produce BPSK from a quadrature modulator, you only need one input. The other input can be held at a constant value. For example, if Q is set to zero and I varies between +1 and –1 then the output is BPSK. That is not intuitive to all people, certainly not to me. The I and Q inputs are used to set the amplitudes of

the Cosine and Sine Local Oscillators. The local oscillators are then added to produce the output.

BPSK generation in this way is illustrated in the waveforms plots below, which show sine and cosine waves with 8 samples per cycle. Notice the first peak in the "SUM" or output waveform moves pi radians or 180 degrees from Figure 6 to Figure 8. Figure 7 shows I at -0.75, illustrating that the phase moves smoothly from one position to the other.

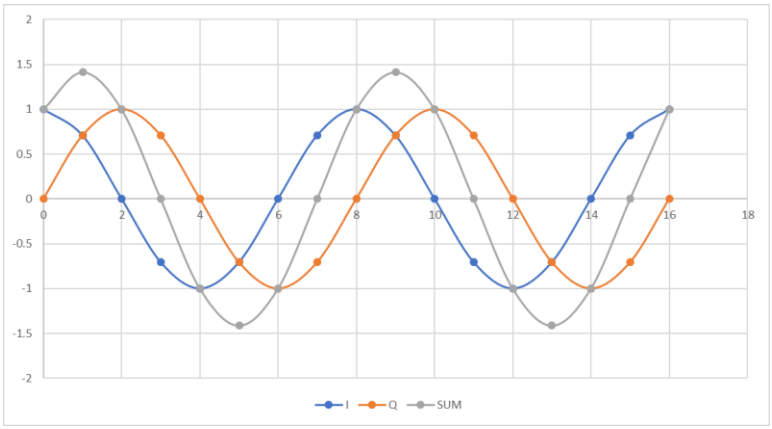

Figure 6 – IQ Modulator when I is at +1 and Q held at +1

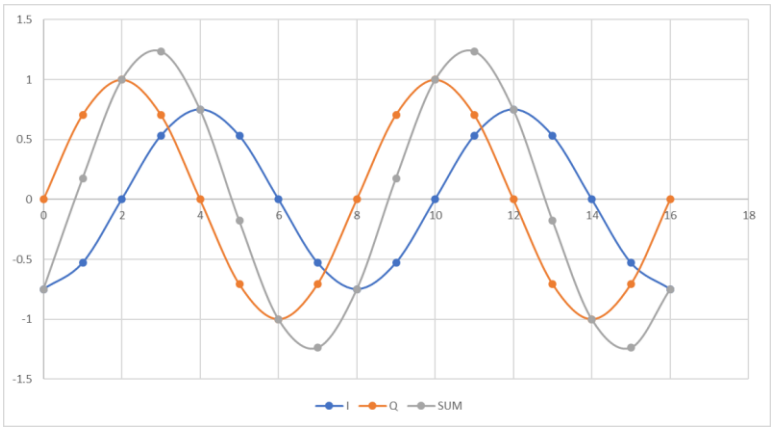

Figure 7 – IQ Modulator when I is at -0.75 and Q held at +1

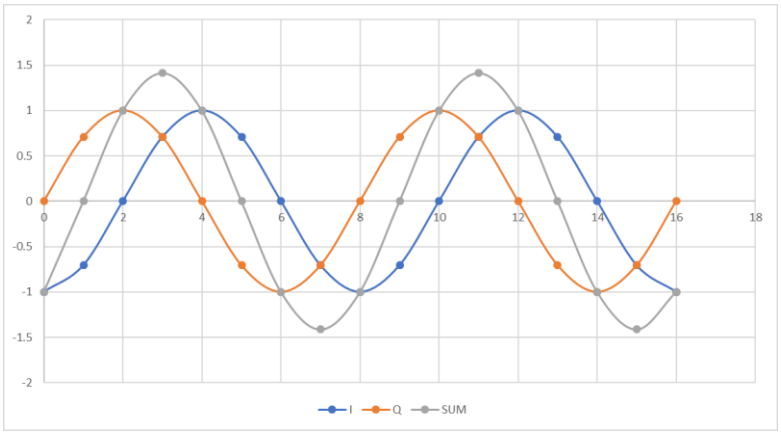

Figure 8 – IQ Modulator when I is at -1 and Q held at +1

IQ vs Balanced Mixer

Side by side testing was performed with a balanced mixer as the modulator, and an IQ modulator.

Here are our bits filtered with a root raised cosine filter.

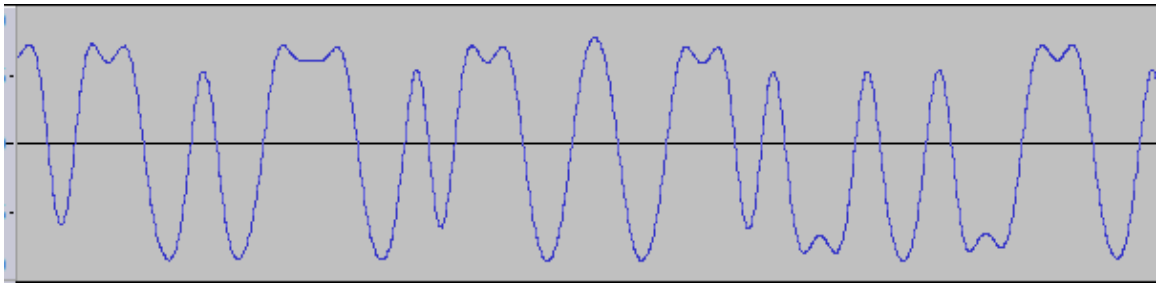

Figure 9 – Bits Filtered with a Root Raised Cosine Filter

When we play them through the IQ modulator, here is the spectrum. The signal was set to peak at -75dBm.

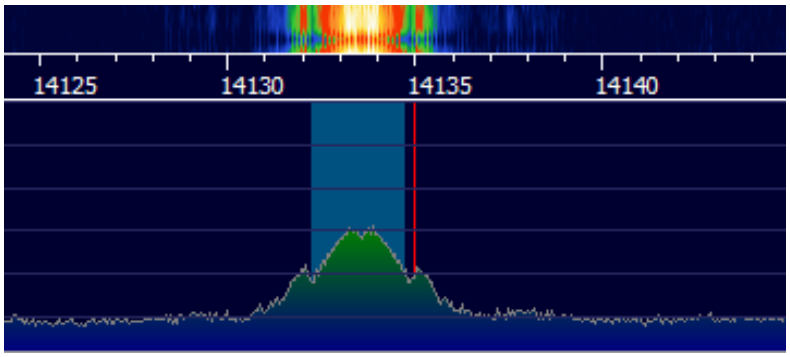

Figure 10 – Spectrum of BPSK Signal from IQ Modulator with Filtered Bits

Some careful measurements show the IQ modulated signal is 25dB down at +/- 1.77kHz. So it is 3.5kHz wide. The signal decodes well.

When we play the same audio through the balanced modulator we still get a decent signal, but it is not as clean as the IQ modulator. Again the signal was set to peak at -75dBm.

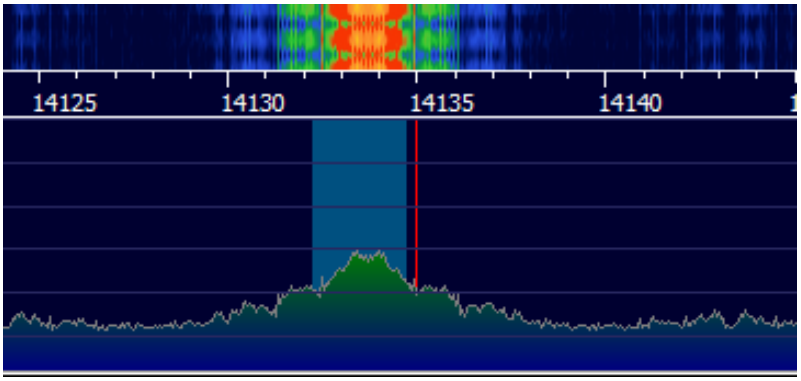

Figure 11 – Spectrum of BPSK Signal from Balanced Modulator with Filtered Bits

This signal is 6.4kHz wide at the -25dB point. It is nearly twice as wide. It decodes just as well, but the bit SNR is lower than the IQ modulator. These tests are shown in the graphs below, where the green line is the average. These were captured as the bits were decoded in FoxTelem.

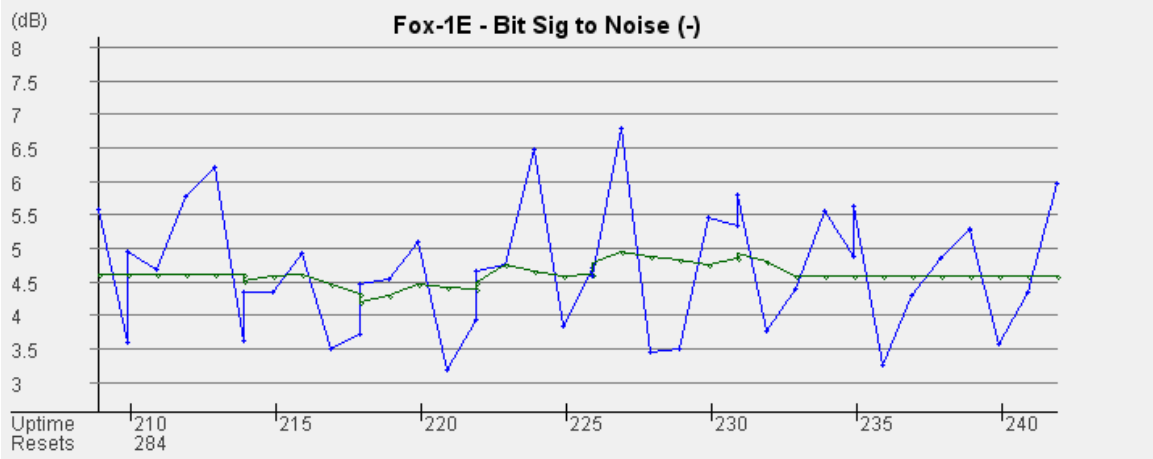

Figure 12 – Eye SNR for IQ Modulator

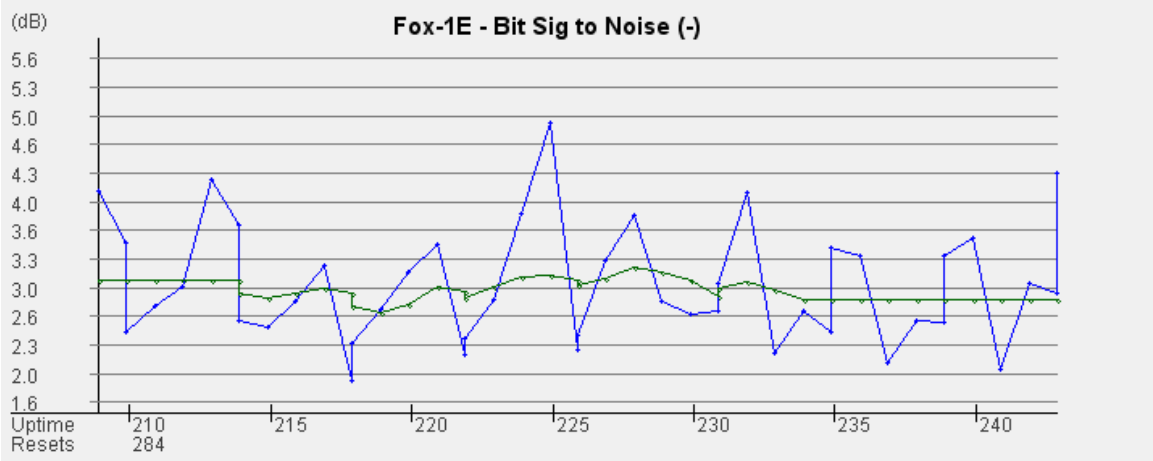

Figure 13 – EYE SNR for Balanced Modulator

The LTC5599 quadrature modulator

We choose the Linear Technologies LTC 5599 quadrature modulator as the BPSK balanced modulator. This chip had several key features that met our requirements:

- Works at our IF of 45MHz
- Low current consumption – 8mA if gain adjusted to minimum
- Configurable from our spacecraft IHU via a Serial Peripheral Interface (SPI) bus, which was already part of our spacecraft architecture
- Adjustable gain
- Adjustable carrier suppression to compensate for tolerances in components

It also has some useful additional features:

- On board telemetry such as temperature
- Able to support more complex modulation schemes in the future

The block diagram of the LTC5599 is shown below.

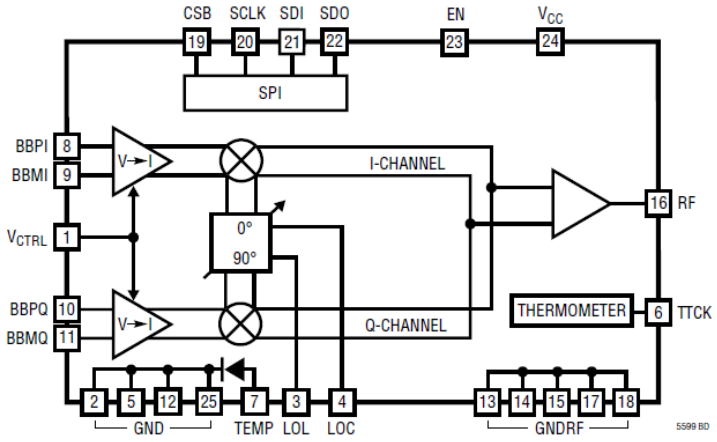

Figure 14 – LTC5599 internals

We needed to supply the LTC5599 with a balanced input and picked the Texas Instruments THS4531. This is a differential operational amplifier. It floats the IHU data bits around 1.4V as a balanced signal. This matches the requirements of the LTC5599.

A 45MHz Mercury Oscillator was chosen for the local oscillator. This is fed to the LTC5599 Local Oscillator port through a diplexer, as recommended in the data sheet.

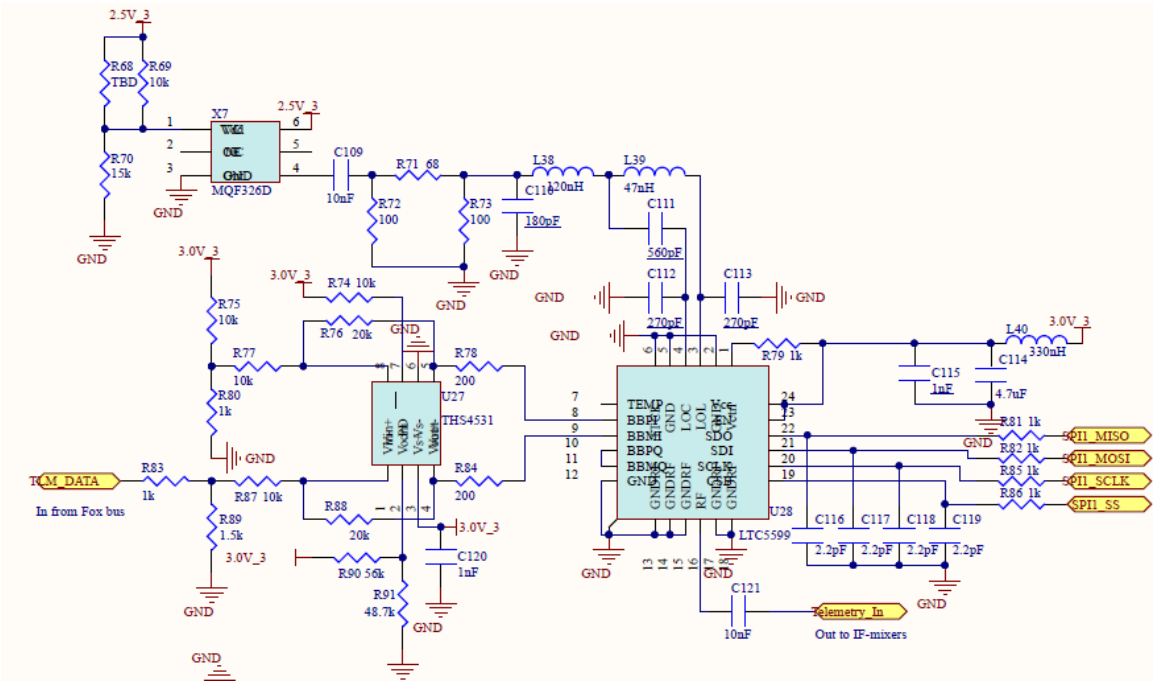

Figure 15 – BPSK Modulator for Fox-1E from 2017 Symposium Proceedings

Adjusting the Carrier

The diagrams below show the BPSK signal from the IHU before and after adjusting the carrier. We can adjust the I and Q offsets through the SPI interface to the LTC5599. We can also adjust the gain from the IHU and hence set the amount of power fed to the telemetry transmission.

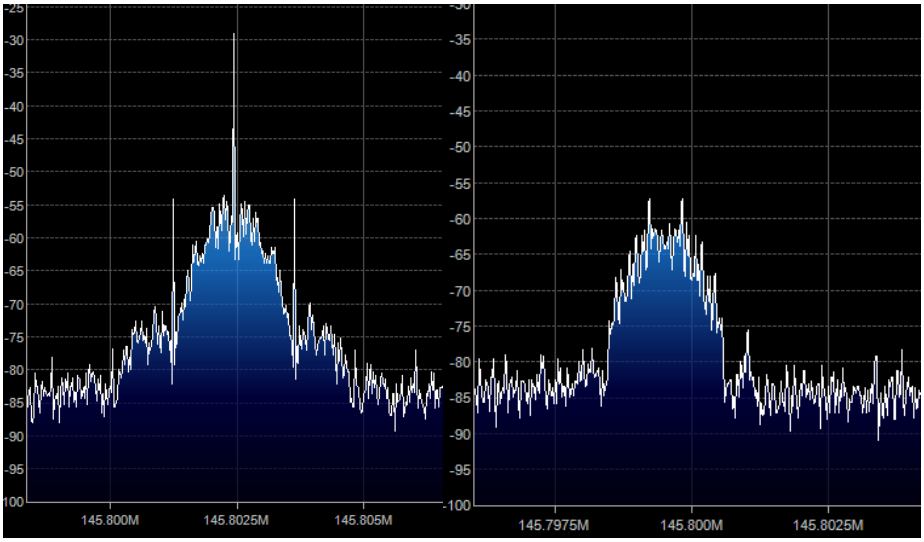

Figure 16 – BPSK Modulation before and after carrier suppression by the IHU

Part2: PSK Demodulator – using FoxTelem

Generating the PSK modulation is less than half the problem because decoding on the ground is always harder than encoding in space. This section discusses the decoder needed for PSK.

The data is encoded at 1200bps and has been Double Sideband modulated onto a 45MHz carrier and then mixed up to our 435MHz telemetry frequency for the spacecraft. Demodulation of a Double Sideband suppressed carrier signal is best achieved by mixing it with the original carrier. The two sidebands add and we get 3dB of gain. The signal can also be demodulated by an SSB demodulator, from a real radio or an SDR, but the 3dB of gain is lost. Either USB or LSB can be used in that case.

If the carrier is mistuned, even slightly, then the demodulation is impaired. With a small spacecraft, where the downlink frequency changes due to thermal conditions, we can't rely on a Doppler calculation to tune the carrier. We need to follow the signal accurately and insert the required carrier to demodulate it.

Coherent IQ Decoder

Coherent demodulation is more efficient than a non coherent decoder, especially with noisy signals (Best, 2007). Coherent demodulation requires not only recovery of the carrier but exact recovery of the phase of the carrier. Recovery is best achieved with a PLL and for BPSK, where the carrier has frequent 180 degree phase changes, it is recovered with a Costas Loop.

Historically the Costas Loop did not have a lot of support because it uses a quadrature oscillator. Like the phasing method of SSB, it relies on precise components and fell out of favor in analog designs. SDRs have brought the phasing method back into fashion because of their ability to simulate precise values and the Costas loop receives the same benefit.

A Costas Loop was added to the FoxTelem IQ receiver with the block diagram below.

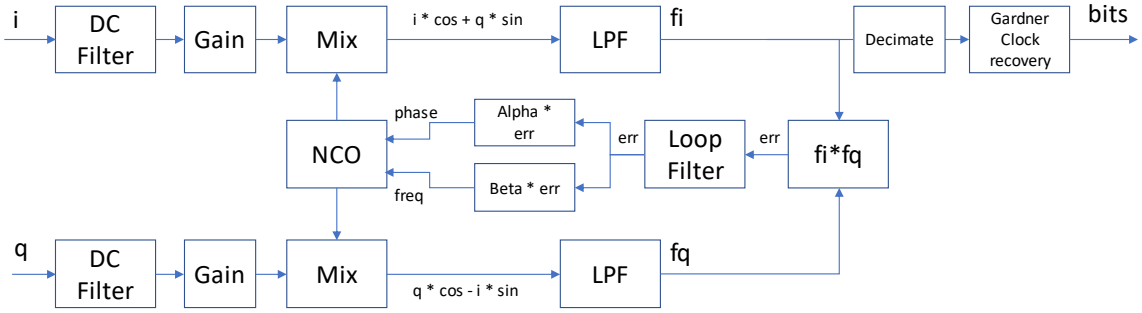

Figure 17 – FoxTelem Costas loop block diagram

I and Q samples are taken from the SDR receiver, typically a Fun Cube Dongle or an RTL Dongle. FoxTelem mixes (in software we do a complex multiply) the I and Q values with the Cosine and Sine values of the Numerically Controlled Oscillator (NCO). Which is a look up table of sine and cosine values that we step through at the sample rate.

The I output is then the recovered bit stream and an unwanted component at twice the NCO frequency. A Low Pass filter at the bit rate leaves us with the recovered bits, called “fi” in the diagram above.

The Q output is the phase error, again with an unwanted frequency component that we filter out. “fq” is zero when we are exactly in phase with the bit stream. It is non zero otherwise and proportional to the phase difference. The sign changes depending on the bit value, so we multiply fq by fi to neutralize the sign change. This gives us an error signal which tells us which direction and how much to move the phase to align the carrier.

The Costas Loop feedback is controlled by two key parameters which set the gain of the loop. The first is Alpha, which is a weighting of the error signal and is used to adjust the phase of the NCO. Alpha was set to 0.1.

The second is Beta, which is proportional to alpha squared and is used as a weighting of the error to control the frequency of the NCO. Beta was initially set to 16 * alpha * alpha and as high as 1024 for large frequency ranges.

These two parameters are required because this is a second order loop. We can not get the loop to converge reliably with a simple gain value.

The low pass filters in the arms of the Costas loop needed to be very fast with little delay or the loop would not track. There were implemented as 1200Hz 0.5% ripple 4 pole Chebyshev Infinite Impulse Response (IIR) filters. (Following a design from Smith, 2003)

The Loop Filter is simpler still and is required to smooth the error signal. It is a Single pole IIR . (Smith, 2003)

FoxTelem is shown below locked to the carrier frequency with the Costas loop in operation. The double sideband demodulation has recovered the bits. Note the raised cosine shape.

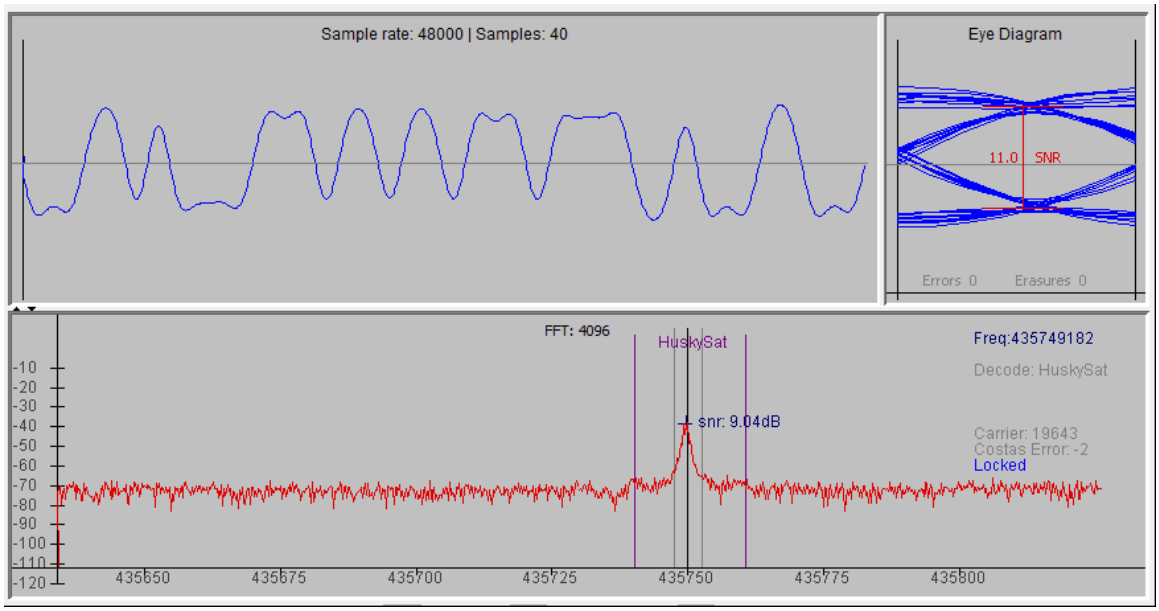

Figure 18 – FoxTelem with Costas loop locked to PSK signal

False Lock

The Costas loop frequently locked onto slightly the wrong frequency as shown in the FoxTelem debug output below. This is a false lock and is common when the frequency error is of the same order as the bit rate. In the example below it is locked 600Hz off. This is a serious issue that makes the Costas Loop decoder unusable in about 25% of lock attempts.

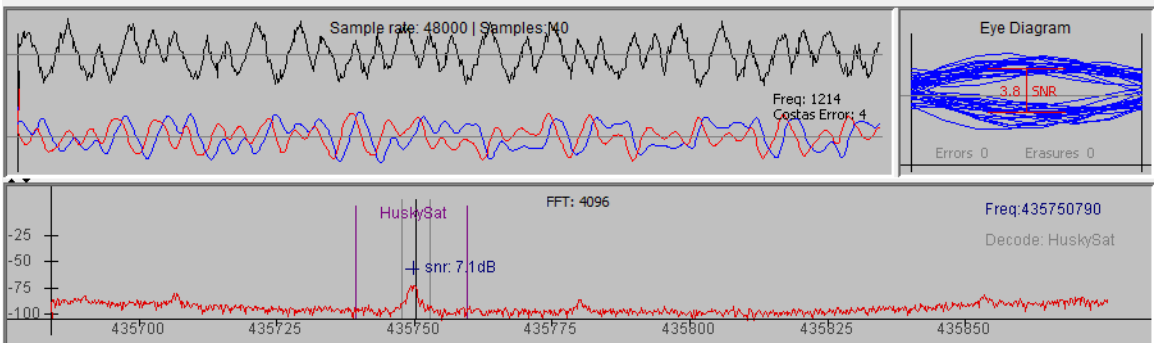

Figure 19 – FoxTelem showing False Lock, and debug information. The black trace is the psk signal, blue trace is I and the red trace is Q (the error signal). Q should be zero, but it is not.

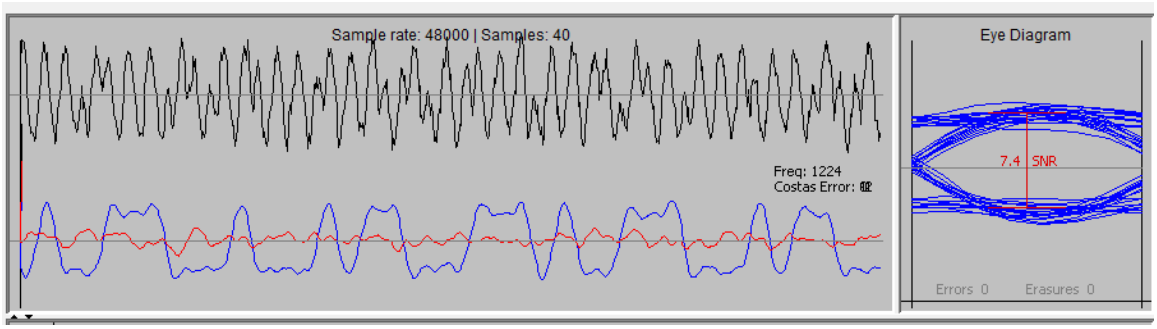

Figure 20 – FoxTelem locked onto carrier

Tom McDermott, N5EG, recommended a review of the patent literature and in particular US Patent US4713630A (Matthews, 1986). This is an expired patent by David Matthews that implements a false lock defeat mechanism. This was originally implemented in hardware but looked like a good candidate for a Software solution.

The original design is shown below.

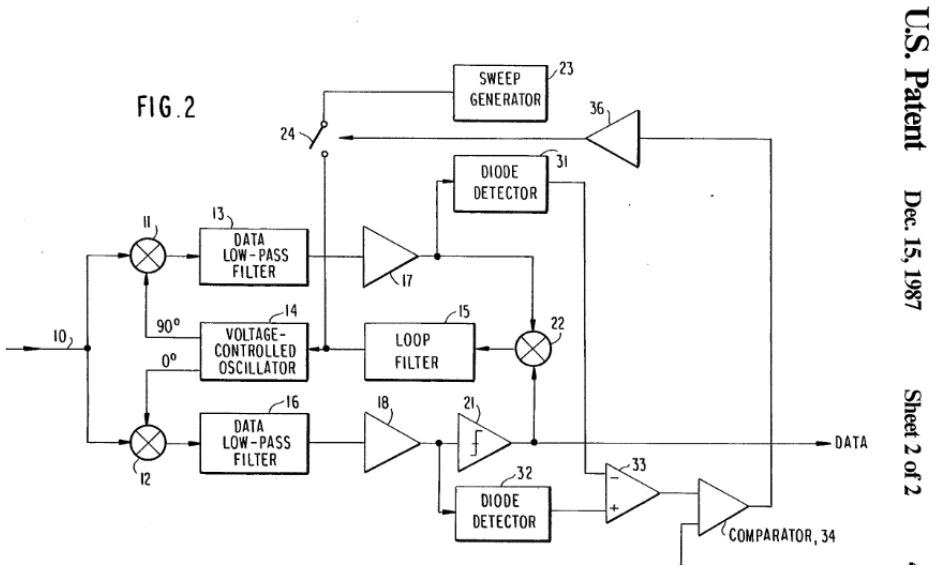

Figure 21 – Costas Loop that defeats false lock from expired US Patent

Implementing this in software was straightforward. "Diode Detection" needs to be full wave rectification and in software is as simple as this:

```
double fullwaveRectify(double in) {
   if (in < 0) return -1*in;
   return in;
}
```

The Costas loop was modified to calculate a "locklevel" value from the filtered signals fi and fq. This worked best if some automatic gain control was used.

```
ri = fullwaveRectify(fi*gain);
rq = fullwaveRectify(fq*gain);
lockLevel = ri - rq;
```

The lock level was summed over a bit and used as a control signal. When it was above a threshold e.g. 5, then the loop was locked, otherwise it is close to zero.

When the loop is not locked then the decoder scans the expected frequency range. In software we just increment the frequency of the NCO by a fixed amount. I had to determine experimentally how fast the decoder should scan so that the Costas loop will still lock when it is at the right frequency.

This design works and false lock is now prevented.

Clock Recovery

With the Costas Loop implemented we are left with the issue that the bits are not centered. The screen shot below shows the first few demodulated bits from a signal, together with a small spike showing where FoxTelem made the bit

decision. We can see that it is almost in the center of the bit. But as the bits flow past, the decision point continues to scroll to the right moving from one bit to the next. This causes the eye diagram to continually scroll and nothing is decoded.

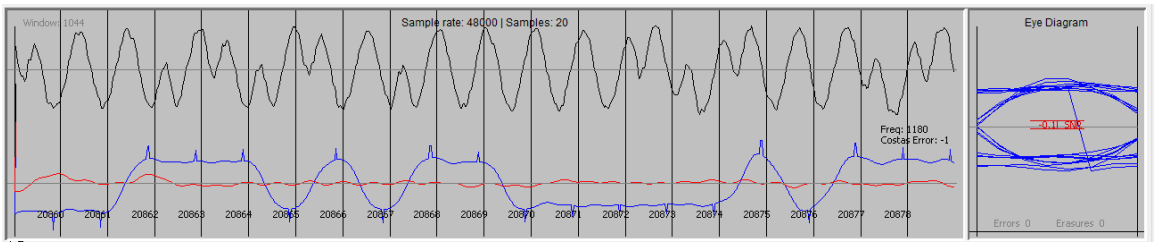

Figure 22 – FoxTelem showing Bit misalignment in "Debug Values" mode

It might not seem obvious, but just because we have recovered the carrier does not mean we have aligned with the clock that the spacecraft used to create the bits. The clock is nominally 1200Hz, but it is subject to thermal variation as it is based on the crystal oscillator of the IHU. The bit decision point and the eye diagram may scroll in one direction or another depending on the speed of the IHU clock compared to the clock in the decoder. If we do not compensate, then nothing will decode.

Gardner Clock Recovery

To recover the clock and adjust our timing we count the samples as they come in and remember where we are in the bit. In the illustration below we show three sampling points. Yn-2 is the value of the previous bit, in this case -1 indicating a zero bit. Yn is the the value of the current bit. Yn – 1 is half way in between. In the example below we know that our bit is nominally 4 samples long, so we count from 1-4 in a loop. When the counter is 2 we sample the bit, when it is 0 (or 4) we take the middle sample.

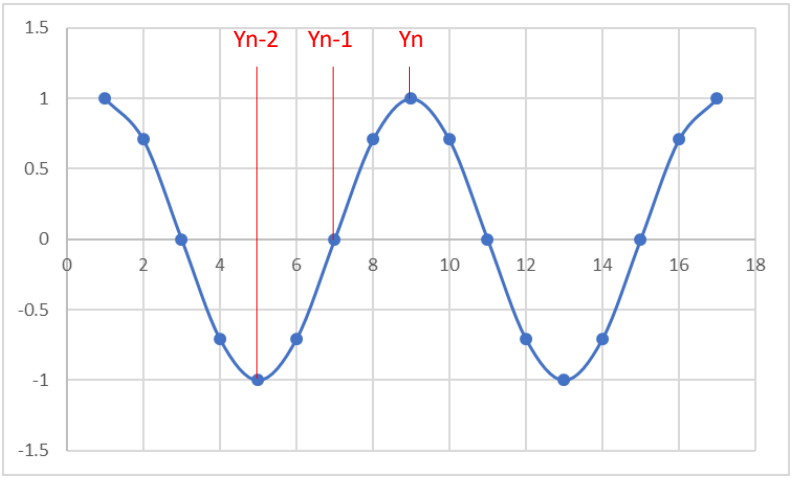

Figure 23 – Sampling points for Gardner Clock Recovery

The error signal is then given by:

Clock_error = (Yn – Yn-2) * Yn-1

If the clock error is positive then our sample is late. In the example below we see that the error is (0.75 - -0.75) * 0.75 = 1.125. So we adjust our sampling so that our next Yn sample point will be at sample 13 and not sample 14. If the clock is early then our error will be negative and we do the opposite.

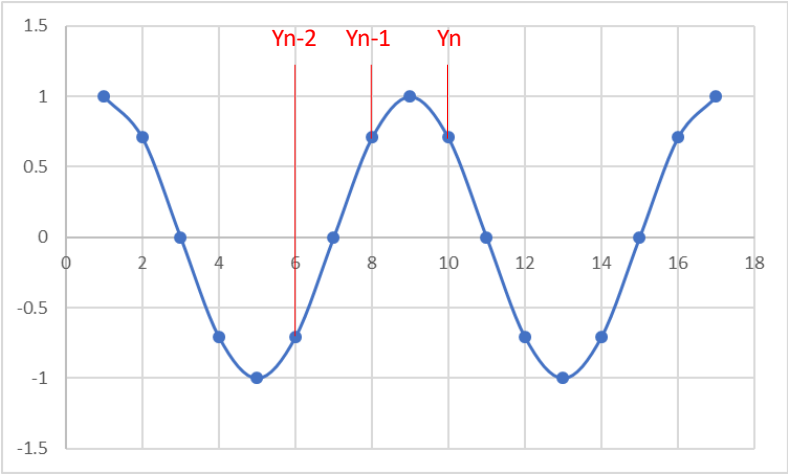

Figure 24 – Late sampling in Gardner Clock Recovery

In the clock recovery algorithm we have to make sure that we don't accidently sample Yn or Yn-1 twice when we adjust our position in the bit. Assuming that does not happen, then the Gardner clock recovery algorithm works well. Bits are recovered and sent to the RS Decoder for Forward Error Correction and eventual decoding.

References

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[2] James Miller G3RUH (1991), The Shape of Bits to Come. *Amsat-UK's Oscar News, 1991 Apr No.88 p.29-37*
[3] John P. Costas (1956), "Synchronous communications". Proceedings of the IRE. 44 (12): 1713–1718
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[3] Roland E. Best (2007), Phase-Locked Loops: Design, Simulation and Applications, 6e
[4] Steven W. Smith (2003), Digital Signal Processing, A practical guide for Engineers and Scientists
[5] Richard E. Lyons (2011), Understanding Digital Signal Processing, 3e
[6] David Matthews (1986), BPSK Costas-type PLL circuit having false lock prevention. US Patent US4713630A.

Fox-In-A-Box: An Easily Deployed Satellite Telemetry Receiver

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Abstract

All the Fox satellites are or will be deployed in high inclination orbits. One disadvantage to these orbits is that there are several orbits per day that pass over largely unpopulated areas (or with a low ham population at least). During these orbits, the AMSAT server receives little telemetry. To partially solve this problem, we have developed an inexpensive, small, easy-to-deploy telemetry station which can be sent to remote locations with only power, an internet connection, and an interested but unskilled volunteer. Building such a station is also an easy and inexpensive way to get involved in satellite telemetry collection anywhere. This paper describes the design of that station, which we call "Fox-in-a-Box", shortened occasionally to FIAB.

Motivation

The orbits employed by all the Fox satellites are at a high angle to the equator. You can think of the satellite traveling in a plane that is at an angle to the earth's equator. At first approximation, the planes stay stationary while the earth rotates under them. Thus, essentially every place on earth passes through the plane of the orbit twice each day. This is an advantage to worldwide hams who want to use the satellites. However, looking at a globe of the earth, you also see that many plane locations pass over areas with low populations of amateur radio operators. For example, one possible orbital plane takes the satellite over the middle of the Pacific Ocean, parts of western Russia, and Africa (depending on the exact orbit angle).

If we miss a few hours of data on one of the first 4 Fox satellites (AO-85, AO-91, AO-92, and Fox-1Cliff) during normal operation, it is not a large problem. However, there are several cases where having more data could be important:

- When the satellite is first launched, we wish to keep an eye on it, and on the results of our commands. More stations makes commissioning faster.
- If the satellite does something unusual (for example, occasionally AO-85 has entered safe mode unexpectedly) we can know sooner and fix the problem by commanding. More data may help us find the problem and fix it in future satellites.
- More data will help us understand the behavior of the satellite better

In addition, as described in a paper last year[1], Fox-1E and some future satellites will be transmitting Whole Orbit Data (WOD) continually. WOD is collected each minute, and put into a circular buffer from which it is transmitted multiple times before being overwritten. To reduce the likelihood of losing WOD, a few stations along every orbit would be desirable.

[1] Fox-1E (RadFxSat-2) Telemetry, Burns Fisher, AMSAT Symposium Proceedings 2017

Over a few beverages at the Houston Symposium (as I recall) Douglas Quagliana, KA2UPW/5, mentioned that a remote telemetry station in Antarctica would be a wonderful thing to have and would solve several of these problems. The idea of a deployable telemetry station stuck in the minds of several of us; in fact I mentioned it at my talk last year.

A Raspberry Pi becomes Fox-in-a-Box

A few years ago, Chris Thompson G0KLA, author of FoxTelem, found that FoxTelem would run on a Raspberry Pi. After some experimentation he deployed an overclocked Raspberry Pi 3 running FoxTelem with a FunCube Dongle Pro+ and a 2M Lindenblad antenna at his vacation home in Canada, and made it accessible with SSH and VNC so he could "tinker" remotely.[2]

Early FIAB

At the 2017 Symposium, I mentioned KA2UPW's idea and my desire for remote stations as part my talk about Fox-1E telemetry. I was surprised and pleased when Craig, KL4E, suggested that he might have a location to deploy a station in Hawaii—an ideal location in the middle of one of our "dead orbits".

Suddenly Chris and I had some additional motivation to develop a more general Fox-in-a-Box based on his initial remote telemetry station.

Requirements

We started by assuming that many remote locations might be hosted by folks who were willing to be helpful for an "interesting" cause, but who were not necessarily hams, nor amateur satellite enthusiasts. In addition, the locations might not be places to which any of us could easily travel. Thus we wanted the deployment to be "plug and play" and we wanted to minimize the annoyance factor once the deployment had happened.

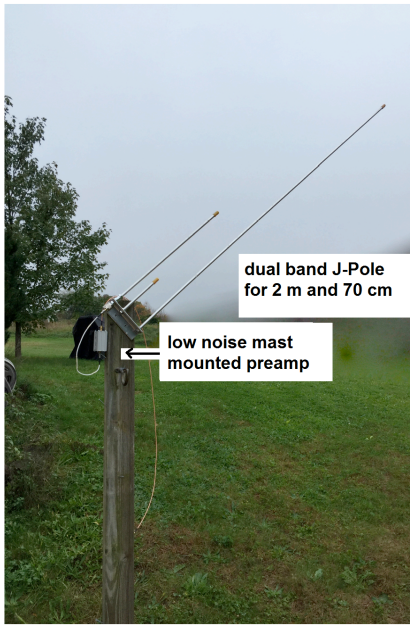
Eventually, we came up with 5 major requirements:

- It must be simple to deploy. A plug-and-play operation is best with minimal installation requirements, no moving parts, and no major special requests of the host, both for installation and for normal operation.
- It must not be "annoying": Flashing lights, screen displays, etc. are out; otherwise, the station would be thrown out of the host's QTH quite soon.
- Low cost: If we are going to deploy multiple of these either on our own or AMSAT's dollar, we want to keep the cost down
- Reasonable reception. We can't expect a beam and Az/El rotator, but we do want to get telemetry from less-than-ideal passes. Otherwise there is no sense in doing it.
- 2m and 70cm capability. Fox-1a through d are U/v birds, but Fox-1E is V/u, so we need both bands.

[2] See http://www.g0kla.com/foxtelem/foxtelem_on_pi.php

Antenna Tradeoffs

As always with such an endeavor, there are tradeoffs to be made. An obvious simple antenna choice is the omnidirectional and (mostly) circularly polarized M2 Eggbeater. However, that antenna is reasonably expensive, can't be shipped assembled, and requires some work to assemble it. It is also rather ungainly to install and is only single-band. So we started thinking about others.



Antenna Test Setup

An Elk antenna solves the multi-band problem, and is not terribly expensive. However, as a directional antenna, we would require a rotator to follow the satellite. Even an azimuth-only rotator system with a fixed elevation was just too complex to ask a host to deploy and too likely to need maintenance.

Like G0KLA with the original FIAB, I have always had very good luck with a homebrew AA2TX EZ Lindenblad antenna. It is circularly polarized and has more gain at the horizon than overhead. And while it is only single-band, the 2m and 70cm versions are stackable. However, both versions are also ungainly and somewhat fragile for shipping whole (not to mention complex to fabricate despite their "EZ" name).

Finally my investigation came up with the Arrow dual-band J-pole. It covers both 70cm and 2m, it comes in a box pre-assembled, it is reasonably simple to mount, and it is quite inexpensive. But given its lack of circular polarization, how well does it work? I acquired one for my backyard and was pleased to see that it does surprisingly well! Its performance was obviously not as good as my tracking beam, but it was comparable to the Lindenblad for some passes.

Feedline, Preamp, and SDR Tradeoffs

We wanted to use a small, flexible feedline, again to make the system easier to deploy (smaller holes, fewer turn radius restriction, etc.). We also wanted to make the feedline long enough so that the SDR and Raspberry Pi could be placed inside the house without too many restrictions. This means feedline losses, so we wanted a preamp at the antenna. To reduce the installation complexity, the preamp should be powered through the feedline via "phantom power", ideally supplied by the SDR rather than by a separate bias-T, to reduce complexity[3]. Finally (for this section) we needed to choose software-defined radio (SDR) hardware that would plug into a USB port of the Raspberry Pi.

The choice of SDR was reduced by which available SDR devices work with FoxTelem: FunCube Dongle Pro+ and RTL-SDR (the latter not fully supported yet, but usable). The RTL-SDR is far less expensive than the FCDP+; however the RTL-SDR has less effective band filtering and dynamic range. We felt that if we used the RTL-SDR, we needed an effective band-pass filter on the

[3] N9IP recently suggested an even simpler setup: Power the Pi with PoE (Power over Ethernet) and place the Pi and FunCube Dongle in a weatherproof box near the antenna with no preamp.

preamp, which in turn would imply that we needed a separate preamp for each band. Both of these SDRs can provide phantom power, but only at 5V (from their own USB power).

The choice of preamp was thus related to the choice of SDR. With the RTL-SDR we needed two preamps with good filtering, for example the ARR or SSB preamps. In addition, we would require diplexers, and a 12V bias-T. The price quickly added up. With the more expensive FCDP+, we could get away with a single wide-band preamp. I use the AMSAT wide-band preamp on my home system with a separate 12V power feed, but some searching found a wide-band preamp powered by 5V phantom power: The Uptronics Wideband Preamp, available from Airspy.us. The combination of FCDP+ and wideband preamp turned out to be less expensive than any combo with the RTL-SDR, so that was our choice.

Remote Connections

G0KLA opened a port in the network infrastructure of his remote location to access the FIAB via direct VNC (which displays the screen as though you were looking at a monitor plugged into the Pi) and SSH (which allows one to type commands directly to the Linux operating system on the Pi.) One can also use SSH to copy files like a new version of FoxTelem to the remote system.

Opening a port requires one to access the local Internet gateway and make changes that most people are unfamiliar with. So once again, we looked for a simpler solution. I decided to use the specific brand of VNC called RealVNC. The RealVNC server is pre-installed on the Pi, and most importantly for this purpose, operates via an intermediate server so that no special port is required to be opened.[4] RealVNC also allows file transfers, and on the screen you can run a terminal and give Linux commands.

Note that using RealVNC to a Raspberry Pi within your local area network (e.g. within your house) does not require using the server in the middle.

Raspberry Pi

We chose the Raspberry Pi 3B+ for FIAB. The 3B+ is fast enough that no overclocking is required, and this seemed better for a remote deployment, especially in a potentially hot location.

Initial Assembly and Test

Chris and I first acquired the parts and I assembled them into a Fox-in-a-Box at my QTH. I mounted the antenna and preamp on a 2-by-4 that normally holds a birdhouse in my backyard. The location is not ideal since my house blocks nearly 180^0 of view, but that meant that the antenna could "see" about 180^0 toward azimuth 315 (NW). I ran a 25' (LMR240) feedline in through the window and connected it to the FunCube Dongle and Raspberry Pi placed on a chair near the window.

[4] Most local Internet hubs allow a computer inside the local network to initiate a network transfer of any sort, but block most externally initiated transfers. With RealVNC, the Pi initiates and keeps open a connection to the intermediate server, and the viewer connects via the intermediate server.

For terrestrial use, the J-pole is normally mounted vertically (and the radiation pattern is null straight up). I wanted to experiment with angles, so I arranged the mounting such that I could adjust the angle from 0 to 90 degrees. While I did not do extensive quantitative experiments, the system did appear to give better results with the antenna mounted at about a 45^0 angle. In many cases I was getting results as good as the Lindenblad antenna that I use for my permanent telemetry station. [5]

Deploying Fox-in-a-Box_HI

FIAB_HI Installation

As we got close to deploying at the QTH of Tyler Bledsoe in Kailua-Kona, Hawaii, KL4E reminded us that Kona, while a vacation paradise, is not a totally benign environment for antennas and feedlines! In addition to being hot and humid, there is an occasional influx of "Vog", a mixture of fog and somewhat corrosive volcanic gasses. For these reasons, we made sure that all connections were liberally coated with silicon grease as well as being well wrapped with Coax Seal.

Our initial plan was to connect to the home network via hardwire CAT-5 since Tyler did have hardwired network connections available. That way, no remote configuration of the Pi would be required and Tyler would not have to reveal his Wi-Fi password. Once the system arrived, though, we discovered that CAT-5 I had sent was not long enough. In the continued spirit of minimizing the installation trouble, rather than asking Tyler to find and buy some CAT-5, we decided to switch to Wi-Fi. First Tyler plugged in the Pi near his hardwire network connection. I was able to connect to it from my QTH in New England via VNC and set up the Wi-Fi with Tyler's cooperation.

Finally after Tyler mounted the antenna outside and connected the feedline, we started collecting data. At first the quantity was disappointing. While I often get dozens or hundreds of packets during a pass at my QTH, Fox-in-a-Box_HI was getting only 10 or 12 packets per day from 3 satellites. We have concluded that there are three major reasons for the low packet count.

1. The Big Island of Hawaii (indeed essentially all of the Hawaiian Islands) has a large volcanic mountain in the middle. Thus FIAB_HI can see only the western sky.
2. The antenna was most easily mounted vertically (see lessons learned) cutting out sky locations directly overhead.
3. Most importantly, the satellites are not heavily used over Hawaii, so the satellite is frequently idling, meaning it only transmits 2 frames every 2 minutes.

The latter hypothesis was confirmed when Leandra, AF1R was visiting Hawaii and activated each of the Fox satellites in orbit. While she got no QSOs, we did notice the packet count from FIAB_HI went way up.

[5] See Fox-in-a-Box_NH on the Fox telemetry leaderboard. It only ran for a few weeks.

It would be interesting to angle the J-pole and point it at the mountain where there will be no reception anyway, but even as it is, we have now believe that the reception is acceptable. When Fox-1E is in orbit transmitting continual WOD data, we hope we will be proven correct.

Lessons Learned and Future Plans

The biggest lesson learned is that more planning and discussion with the host would be ideal. We had two issues that could have been avoided with more discussion:

1. The Ethernet cable problem. We could have saved our host some trouble and from having to give out his password if we had determined ahead of time how long the Ethernet cable should be. Of course, that also requires more time spent on the host's part measuring and planning. It's a tradeoff.
2. The antenna mounting. Tyler had to invent a way to mount the antenna and do more work than we ever intended. I had assumed that the antenna could mount on the side of the house, but it turns out that the roof has a very large overhang on all sides. Had I asked for pictures, I could have seen that and tried to come up with a different solution.
3. Of course it would be easiest to visit the remote location and install FIAB ourselves. There were no volunteers to travel to a difficult location like Hawaii.[6]

For future stations, aside from solving the above problems, I think it is worth experimenting with an RTL-SDR, as well as trying N9IP's idea of using no preamp, and a waterproof external Raspberry Pi. These changes would reduce the cost; the question to answer is how the performance would be affected by the RTL-SDR.

Build Your Own FIAB!

If you would like to build your own inexpensive telemetry station, read on. Not only is it fun, but you also contribute to AMSAT's growing body of data about the Fox satellite performance in orbit, and you will be prepared for Fox-1E when getting more telemetry becomes even more important. If you are in a location with few telemetry stations (far north or southern hemisphere in particular) we would especially like to encourage you to install a FIAB. If you are actually interested in looking at the telemetry regularly, this section also shows you how to build a Fox-in-a-Box with a small screen on the front. Note that this section describes the FunCube Dongle and preamp version. If you experiment with other ideas, we'd like to hear what you have done.

Fox-in-a-Box with FCDPP

[6] Joke

Bill of Materials

Required

- Raspberry Pi 3 B+ with power supply and heat sinks, 32G SD Card
  - Many kits available on Amazon, Canakit, Adafruit.
    For example CanaKit Pi kit and Samsung SD Card) ~$50
  - Raspberry Pi 3 also works, but needs to be overclocked
- FunCube Dongle Pro Plus (http://www.funcubedongle.com) $160

Required in Some Form

- Two meter/70cm Antenna, coax connections
  - I use a home built AA2TX Lindenblad
  - A dual-band J-pole works surprisingly well
    (http://arrowantennas.com/osj/j-pole.html) $49

Nice To Have

- Preamp (Good with long or higher loss feedlines)
  - I use an AMSAT wide-band preamp with separate 12V power
  - For ease of deployment, a phantom power, wide-band preamp from AirSpy
    works well https://v3.airspy.us/product-category/preamps/page/2/ $46
- Raspberry Pi Case
  - To use with screen, on Amazon
    RS Raspberry Pi 7-Inch LCD Touch Screen Case, Black $15-25
  - Or to use without screen (for remote access) -~same price range

If You Want A Touch Screen

- On Amazon: Raspberry Pi 7" Touchscreen Display $75

Building a Fox-In-A-Box The Easy Way – A Prebuilt SD Card Image

- See http://burnsfisher.com/AMSAT/FoxInABox/readme.txt first. It explains some of the following steps in more detail.
- Assemble the Raspberry Pi hardware according to directions with the kit or online. Do not forget the heat sinks! If you plan to use the touch screen do not attach it until everything else is set up.
- There is a prebuilt OS and code image for a Raspberry Pi 3B available. Copy the image file to an SD card in order to avoid the software installation. **Warning**: It is 3 Gigabytes long and then you unzip it to be much larger. It should fit on a 16GB SD card, but surely on a 32GB.
- Install the SD card in your Pi and fire it up. When you are happy, install the screen if you have one.

Building a Fox-In-A-Box The Hard Way – From Scratch

- Assemble the Raspberry Pi hardware according to directions with the kit or online. Do not forget the heat sinks! If you plan to use the touch screen do not attach it yet.
- I suggest that you connect a keyboard, mouse and full size monitor while you set up the system.
- Install the latest Raspbian OS according to directions here:
  - https://projects.raspberrypi.org/en/projects/raspberry-pi-getting-started/2
- Install Java and other required packages as well as FoxTelem. See http://www.g0kla.com/foxtelem/foxtelem_on_pi.php under "Dependencies"
  - Note: Things change with every Raspbian release. You must be flexible and creative figuring out what to install. Google is your friend.
- Decide on a display/control method. Here are some possibilities:
  - HDMI monitor, USB keyboard and mouse

        - Plug them in. You are done!
    - Touchscreen display
        - Follow the instructions to install the touchscreen display. With the case described above, you must also use software to turn the display upside down (edit /boot/config.txt, add the line lcd_rotate=2)
    - VNC (See below)
        - Raspberry Menu/Preferences/Raspberry Pi Configuration
        - Interfaces tab: Check "VNC"
- For more info look at the "readme.txt" from the prebuilt image above

VNC

Unless you only plan to use the FIAB with an attached monitor, keyboard, and mouse, I strongly suggest that you enable VNC, which allows you to display the Pi on the screen of any computer. It works very efficiently and is free with some (not very onerous) restrictions. I have accessed the FIAB in Hawaii from my QTH in New Hampshire with only a minor, non-troublesome delay. Install VNC Viewer on your "other" computer from this URL:
https://www.realvnc.com/en/connect/download/viewer/

If you access your FIAB remotely, you will also need a free account from RealVNC. If you are always on your local LAN, that is not required.

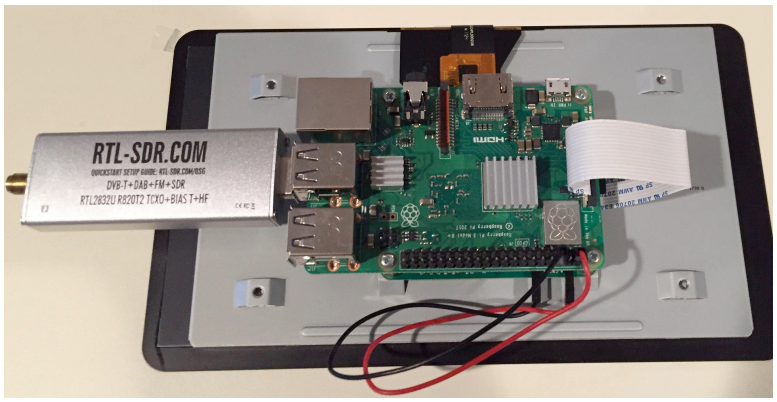
Using the Touchscreen

The touchscreen is quite small, and the standard version of FoxTelem does not handle that size very well. Future versions (such as displayed at Hamvention, Boxboro, and Symposium 2018 and supplied with the prebuilt image) will do a better job, especially if you switch fonts to a small size. The prebuilt image (above) includes a pre-release of one of these future versions.

Starting VNC on the Pi as described above gives you a remote screen the same size as the touchscreen.. Using VNC is far easier than using the touchscreen; if you don't need the touchscreen, don't use it and you can get a more reasonable screen size on VNC using the "resolution" Raspberry Pi preference setting.

Fox-in-a-Box with Touch Screen and FCDP+

It is also possible to create a 'virtual' larger screen, but I have not tried it with the touchscreen to discover its pros and cons. See the g0kla.com URL above under "Headless Operation", and particularly the add-on by WB1FJ.



Fox-in-a-Box with Touch Screen and RTL-SDR

A FLEXIBLE, AFFORDABLE, POWERFUL DIGITAL TRANSCEIVER FOR THE RASPBERRY PI

JONATHAN BRANDENBURG, KF5IDY

ARRL AND TAPR DIGITAL

2018 36TH ANNUAL AMSAT SPACE SYMPOSIUM

DREAMS

How would you like to have a box that is a digital transceiver you can use as a satellite ground station, a satellite simulator, a digital BBS?

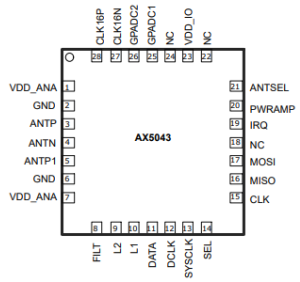
If I wanted to build one, where do I start?

WHAT DO THE FOLLOWING HAVE IN COMMON?

- AMSAT
- Libre Space Foundation
- University of Louisiana
- Portland State University

ALL ARE USING THE AX5043 DIGITAL TRANSCEIVER IC FROM ON SEMICONDUCTOR

- AMSAT
  - Golf-TEE IHU, Golf-1 IHU, CubeSat Simulator
- Libre Space Foundation
  - PocketQube Format Satellite Modules
- University of Louisiana
  - Satellite Beacon, Education Platform
- Portland State University
  - OreSat IHU Transceiver



WHAT IS THE ON SEMICONDUCTOR AX5043?

- A single chip, low-power digital transceiver
- Modulation and demodulation is performed on chip.
- For transmit, the host processor sends the data byte stream. The AX5043 adds optional FEC and modulates for transmission
- For reception, the AX5043 demodulates the signal, validates optional FEC then sends the resulting data to the host processor.

WHAT IS THE ON SEMICONDUCTOR AX5043?

What modulation standards?

- FM
- GMSK
- ASK
- GFSK
- PSK
- MSK
- FSK
- 4-FSK
- AFSK

WHAT IS THE ON SEMICONDUCTOR AX5043?

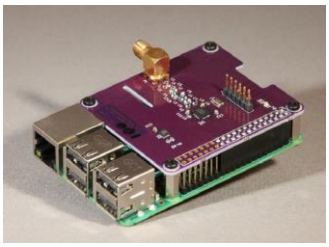
- What frequencies?
  - From 27 MHz to 1050 MHz
- What about output power?
  - 16 dBm (40 mW)
  - Of course, may add an external power amplifier
- What about sensitivity?
  - Example: -138 dBm @ 0.1 kbps, 868 MHz, FSK
  - Example: -108 dBm @ 125 kbps, 868 MHz, PSK

WHAT IS THE ON SEMICONDUCTOR AX5043?

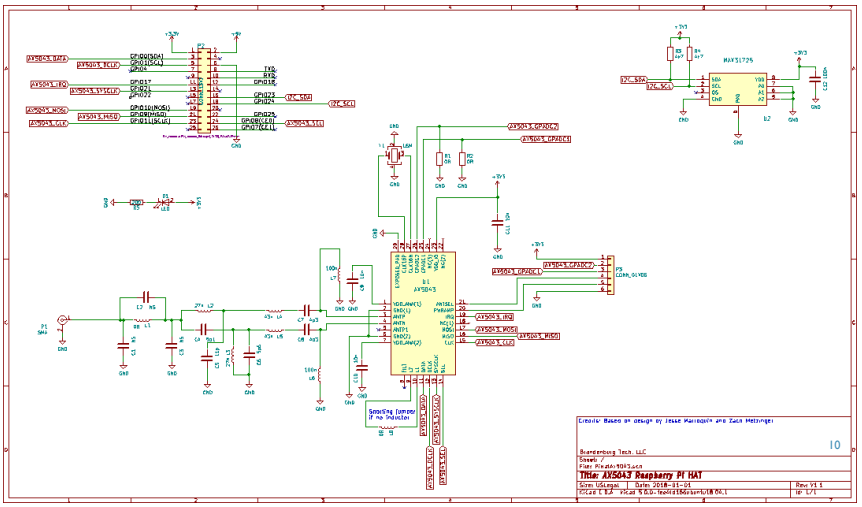
- What about chip power requirements?
  - 6.5 mA – 9.5 mA when receiving
  - 7.5 mA when transmitting at 0 dBm
  - 48 mA when transmitting at 16 dBm
  - 500 nA power-down mode with clock
  - 50 nA deep sleep current

I WANT TO PLAY!!!

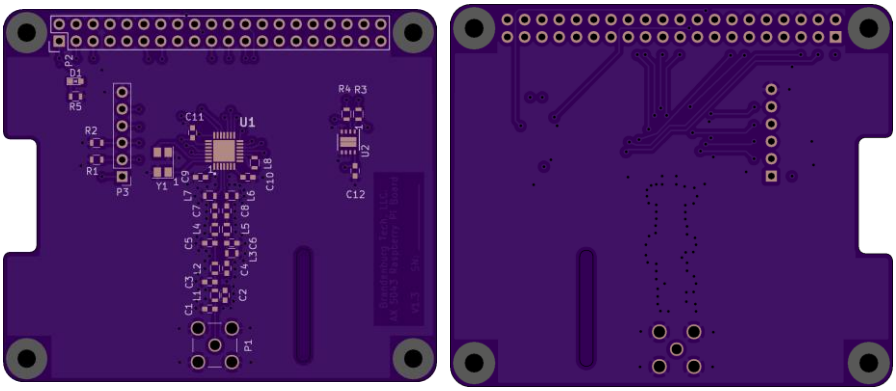
- I do what any of you might do… I create a custom board… for the Raspberry Pi
- Why the Raspberry Pi?
  - It's an affordable experimentation platform
  - It has the peripherals (SPI) to communicate with the AX5043



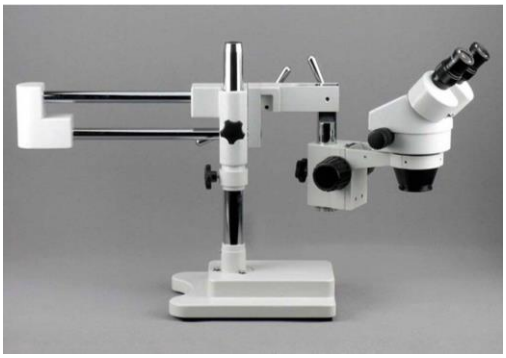
KICAD FOR THE SCHEMATIC AND LAYOUT



OSHPARK FOR BOARDS



HAND ASSEMBLED



12

DOES IT WORK?

- Yes!!!
- Developed several sample applications
  - A chat application at GFSK, 435.3 MHz, 4800 symbols/sec, HDLC encoding, CRC-16
  - APRS frames, AFSK, 435.3 MHz, X.25 frames
    - (I know FSK would typically be used at 435.3 MHz. Will talk about the matching network in a moment)

DOES IT WORK?

- Key Learning Opportunities:
  - The documentation is a "reference" not a "guide".
  - AX-RadioLab application generates register values and sample code.
    - These register values are sometimes completely unexplained.
    - Generated code specific to On Semiconductor AX8052F100, including use of interrupts.

WHAT ABOUT HAM FREQUENCIES?

- What about Ham frequencies?
- AX 5043 data sheet has reference design to match the IC to a 50 Ohm antenna
  - 169 MHz
  - 433 MHz
  - 470 MHz
  - 868 / 915 MHz

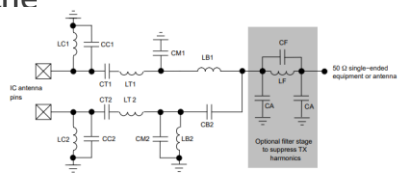
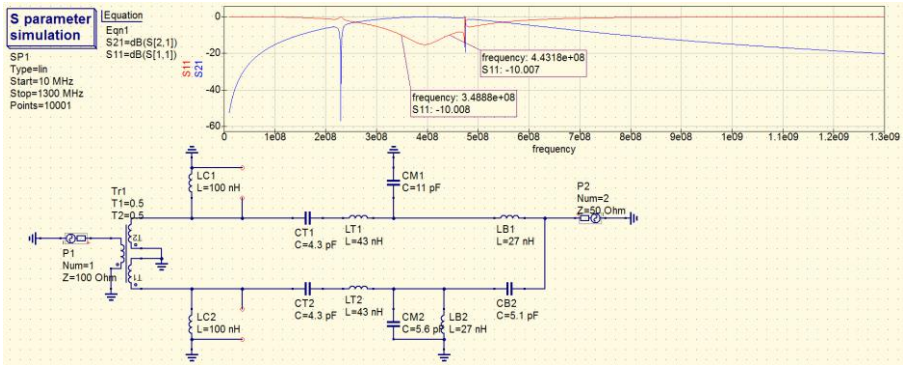


Figure 10. Structure of the Differential Antenna Interface for TX/RX Operation to 50 Ω Single-ended Equipment or Antenna

Table 29. TYPICAL COMPONENT VALUES

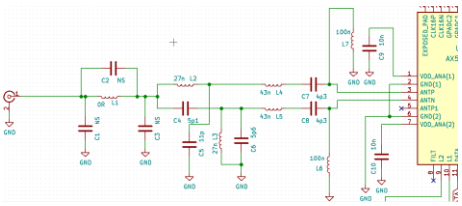
Frequency Band	LC1,2 [nH]	CC1,2 [pF]	CT1,2 [pF]	LT1,2 [nH]	CM1 [pF]	CM2 [pF]	LB1,2 [nH]	CB2 [pF]	CF [pF] optional	LF [nH] optional	CA [pF] optional
868 / 915 MHz	18	nc	2.7	18	6.2	3.6	12	2.7	nc	0 Ω	nc
433 MHz	100	nc	4.3	43	11	5.6	27	5.1	nc	0 Ω	nc
470 MHz	100	nc	3.9	33	4.7	nc	22	4.7	nc	0 Ω	nc
169 MHz	150	10	10	120	12	nc	68	12	6.8	30	27

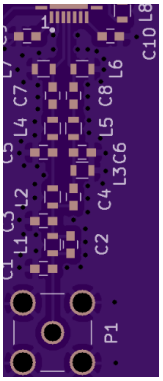
QUITE UNIVERSAL CIRCUIT SIMULATOR (QUCS)



MATCHING NETWORK

- The most interesting part of the schematic is the matching network
  - I populated my boards for 433 MHz
  - Simply populate with different components for other bands





WHAT NEXT?

- Adding a power amplifier
- AMSAT Golf-TEE IHU using NXP Semiconductor MMZ09312BT1
  - 400 – 1000 MHz
  - ~31.7 dB power gain (@ 900 MHz)
- Planning an onboard GPS for beaconing
- Planning a transverter for higher frequencies

I WANT ONE!

- https://github.com/BrandenburgTech/DigitalTxRxRPi
- https://brandenburgtech.wordpress.com/
- AMSAT Store
- I have a few assembled boards
- TAPR - volume assembly
- Build you own!

COST ESTIMATES

Very low volume (e.g., 3)

- $19 for PCB (ouch)
- $12 for components
- $52 for assembly!!!! (this is why I hand assemble)

Moderately low volume (e.g., 100)

- $4 for PCB
- $7 for components
- $8 for assembly

???

Questions / Answers

CREDITS

- Zach Metzinger (N0ZGO), Jesse Marroquin (K5JXM), Bill Reed (NX5R), and Jordan Trewitt (KF5COQ)
  - Design of the Hercules LaunchPad BoosterPack featuring the AX5043
- AMSAT
  - Supporting this platform as the basis for the Golf-TEE IHU

The AMSAT CubeSat Simulator: A New Tool for Education and Outreach

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***Abstract*- The AMSAT CubeSat Simulator is a new tool for education and demonstrations. It can be used in a classroom or training setting to introduce the basics of nanosatellites, or it can be used to teach STEM (Science Technology Engineering and Math) concepts, or it can be a stepping stone in a project to build and launch an actual CubeSat into space. This paper describes a proof of concept prototype of the AMSAT CubeSat Simulator which provides similar functionality to the original ARRL ETP CubeSat Simulator built by Mark Spencer, WA8SME, in 2009. We hope to get useful feedback and suggestions from this paper which will enable us to move ahead with the project.**

I. Introduction

The AMSAT CubeSat Simulator is a new tool for education and demonstrations. It can be used in a classroom or training setting to introduce the basics of satellites, or it can be used to teach STEM (Science Technology Engineering and Math) concepts, or it can be a stepping stone in a project to build and launch an actual flight model CubeSat.

We have observed that too many CubeSats have been "DOA" upon deployment on orbit, which is a shame given the time, effort, and expense that was invested in them. An important use of the CubeSat Sim is to help new CubeSat builders to learn to "crawl before they walk or run." With the assistance of AMSAT, a new group embarking on a CubeSat mission would not start with a "real" flight model (FM) structure, but instead learn or "practice" first by producing either an engineering test unit (ETU) or, before that, with this CubeSat Simulator.

There are many benefits to building a simulator including groups who wish to have a simple, operating, "flight-like" model for education purposes. We believe that educators and AMSAT Ambassadors are our main audience, but others will take notice as well.

This paper describes a proof of concept prototype of the AMSAT CubeSat Simulator which we will refer to as the CubeSat Sim. We hope to get useful feedback and suggestions from this paper and presentation, which will enable us to move ahead with the project. As the current version is a work in

progress prototype, a detailed schematic is not provided in this paper. Instead, high level design considerations and architecture are described. Once it is finalized, a future article in the AMSAT Journal will provide complete schematics and details.

II. Background on ARRL ETP CubeSat Simulator

Mark Spencer, WA8SME, developed a CubeSat simulator about ten years ago, which is the foundation and inspiration for this simulator. The AMSAT Journal published his substantial results in two major articles which are available online [1],[18].

One of the most notable features of the ETP CubeSat Simulator was its many lessons on Attitude Determination and Control (ADAC), which is a critical subsystem of *all* satellites big and small, not just all CubeSats. Mark placed a solar cell on each of the six sides of the cube structure with the primary function to charge the "flight" batteries. He used spreadsheet plots of the output voltage measurements of the cells to determine the spatial orientation and rotation rate of the CubeSat to the source of illumination, and thus it attitude with respect to the earth and an observer on the planet's surface. This served as a crude, but correct, educational method for his series of inquiries and challenges for students to investigate.

Mark not only successfully designed and built the hardware, but he developed a wise philosophy on how to effectively present the material and hardware to teachers, students, fellow Amateur Radio operators and community groups. His goal was (and still is) to promote and facilitate the advancement of space technology literacy. In doing so, Mark cautions that in a school classroom, we must allow the teacher to do the teaching, and to make the connections to the education standards and benchmarks. Thus, AMSAT and the hams ought to only provide instruction to these teachers and the hardware, but should be ready to advise and assist.

III. Goals and Requirements for the AMSAT CubeSat Simulator

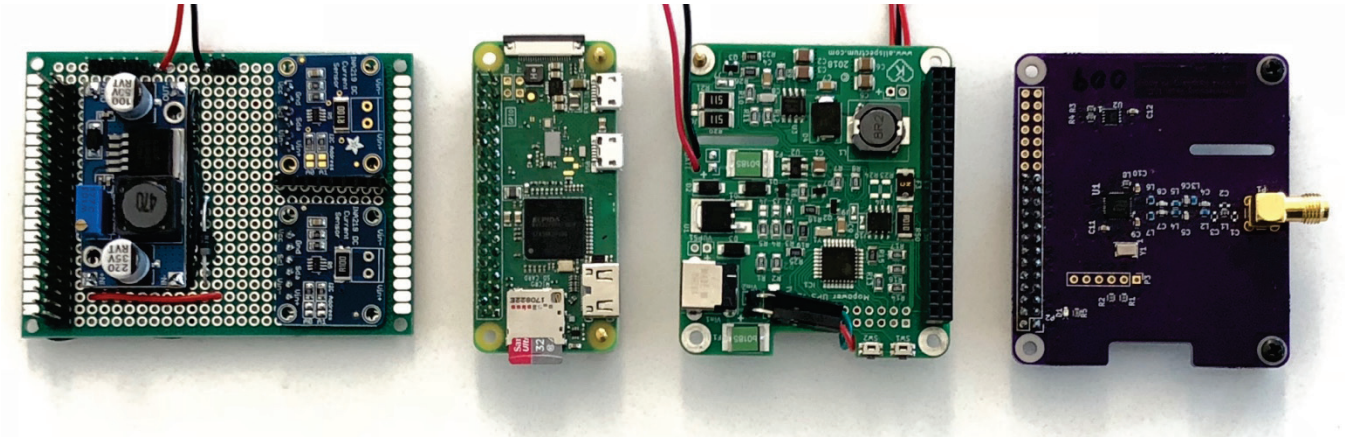
The main goal of the project is to replicate as much as possible the functionality of the original ETP CubeSat Simulator [1]. We have tried to use modern materials and utilize software and general-purpose hardware as much as possible, leveraging Software Defined Radio (SDR) concepts. We have tried to balance cost with performance, usually compromising on the performance to keep the cost of the CubeSat Sim low. Some other goals are listed here:

- Open source all software and hardware developed
- Have a robust design that makes maintenance simple
- Try to have a look and feel that is as close to a CubeSat engineering model as possible
- Try to have functionality that emulates a real CubeSat
- Have a modular design that allows different subsections to be swapped out for alternatives
- Build a community to support and extend the design

Our final goal is to have a proof of concept prototype to show off at the 2018 AMSAT Space Symposium. We believe that with the proof of concept described in this paper we have met most of these goals. Writing this paper and presenting at the Space Symposium are the first steps towards building a community that is excited to make, modify, and extend this CubeSat Simulator.

IV. Simulator Design

The subsystems of the CubeSat Simulator are shown in Figure 1 and described in the sections below.



Solar Power Management	Control	Battery Management	Transmitter
Custom Circuit Board	Raspberry Pi Zero W	MoPower UPS V2	Brandenburg Digital Transceiver for the Raspberry Pi
Monitors solar panel current and voltages for telemetry. Boosts voltage to 15 V to charge batteries. Switches between DC input power and solar power.	Runs software to control simulator. Controls and communicates with other boards using the GPIO connector.	Manages charging of 9 V NiMH battery. Provides power on/reboot/shutdown button and automatically shuts down Pi if battery voltage is too low.	Transmits telemetry signal on 70 cm band using different modulation schemes.

Figure 1. Proof of concept Prototype Boards and Functions

The Control Subsystem, implemented as a Raspberry Pi Zero W [2], controls all aspects of the CubeSat Sim. It collects data on the operation and status of the CubeSat Sim and formats as telemetry and transmits it to the Ground Station for display and analysis. The General-purpose Input Output (GPIO) header allows the boards to be stacked and provides access to the various buses. The stacked boards are show in Figure 2. In this picture, the order of the boards from the bottom is the Solar Power Management board, the Control System board, the Battery Management board, and the Transmitter board. The Battery Management System, implemented using the MoPower V2 UPS (Uninterruptable Power Supply) [3], charges and monitors the NiMH batteries using power from the Solar Power Management Subsystem, and communicates with the Control Subsystem using the GPIO. Battery voltage and current and charging status are reported to the Control System. It also sends shutdown and reboot commands to the Control Subsystem based on button presses. The Transmitter Subsystem, implemented as a Digital Transceiver for the Raspberry Pi board, transmits 70cm telemetry beacon and is configured and controlled by the Control System over the GPIO connector. The Solar Power Management Subsystem, implemented as a custom circuit board, takes up to five solar panels and combines their outputs and boosts the output to 15 V to charge the batteries. It also switches between solar power and DC input power supply to the Battery Management Subsystem. Voltage and current monitoring is provided to the Control System using over the GPIO connector. Solar cells provide power to the Solar Power Management System. The Ground Station, implemented as a PC with RTL-SDR USB dongle and free software, receives and decodes the CubeSat Simulator telemetry. The data can be imported into a spreadsheet (such as Excel), the telemetry data can be analyzed and plotted and used to teach satellite or STEM concepts.

Each of these subsystems is described in more detail in the following sections. The interconnection of the subsystems is shown in the block diagram of Figure 3.

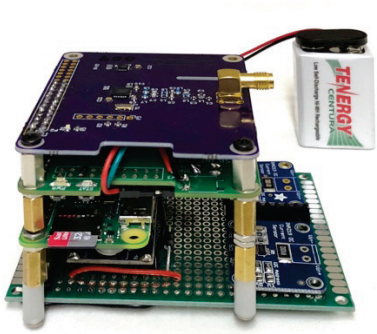


Figure 2. Proof of concept Prototype Stack

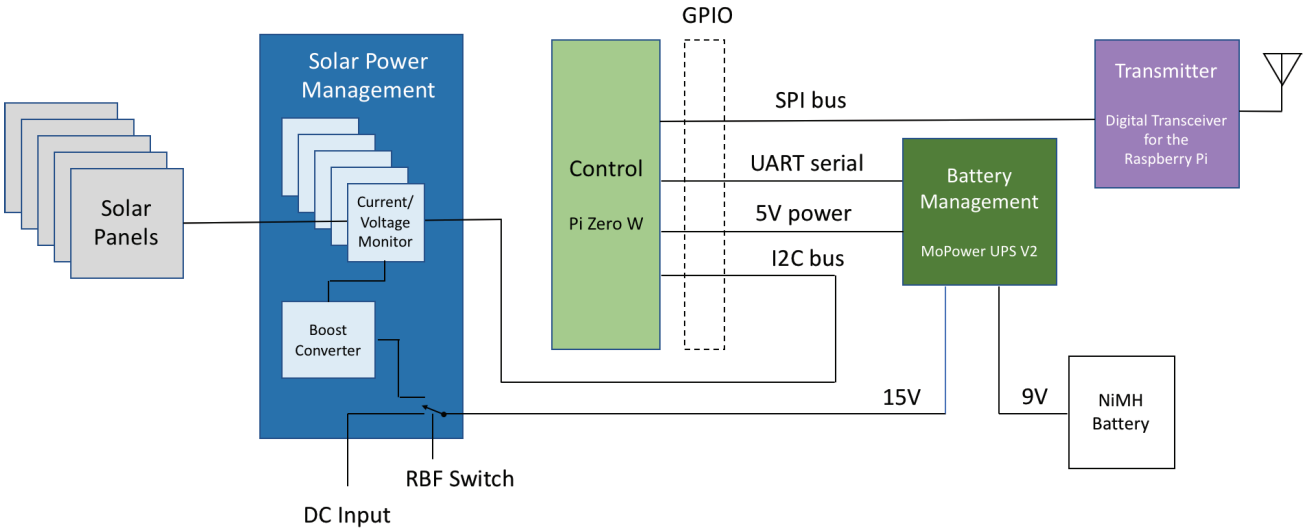


Figure 3. CubeSat Simulator Subsystem Block Diagram

A. Raspberry Pi Zero W

The Raspberry Pi Zero W is a small form factor and low power usage version of the popular Raspberry Pi single board computer, running the Raspbian Stretch version of Debian Linux. It is similar to the common Raspberry Pi 3B and 3B+ but is about half the width and does not have an ethernet port or full-sized USB ports. Instead, it has a micro USB port and a small HDMI port. The Pi Zero W does have Wi-Fi and Bluetooth connectivity. We need to disable the Bluetooth functionality as it changes the clock rate of the Raspberry Pi when the UART is enabled, causing communication issues with the Digital Transceiver for the Raspberry Pi board. The Raspberry Pi does not have a hard drive. Instead, storage is a micro SD card of at least 16GB. During the initial install and configuration, a Raspberry Pi unfortunately needs to be connected to a monitor, keyboard, and mouse. As a result, adapters for the micro USB and small HDMI are needed. However, once the Wi-Fi is configured and SSH (Secure Shell remote login) is enabled, the Pi can be accessed using a PC (running Putty on a PC or ssh on a Mac or Linux) over the network. The Pi Zero W runs on 5 V power which can be provided

via the micro USB or via the GPIO. The Pi Zero draws about 120 mA, compared to about 400 mA for the Pi 3B+.

The Raspberry Pi General-Purpose Input Output (GPIO) interface is used interface with the other boards in the CubeSat Sim. In order to connect multiple GPIO devices to a Pi, either a GPIO expansion board (such as a 3-in-1 expansion board), or the GPIO headers need to be replaced with stackable headers. Stackable headers provide a better form factor without having to offset each board with the expansion board. The Pi Zero W usually comes without the GPIO header pins installed, making it easy to instead install a stackable header. We removed the GPIO header pins on the MoPower UPS V2 board and replaced it with a stackable header.

The GPIO contains the three buses used to communicate with various modules: the UART, the I2C bus, and the SPI bus. The use of each of these buses will be described by the subsystem that uses them to communicate with the Pi.

The software for the Raspberry Pi for this project is open source and available at GitHub [4]. The code is written in C language and has been tested on a Raspberry Pi 3B and 3B+ and Pi Zero W. Instructions on how to download and compile the software is available there. The software is run as a systemd service to automatically start on boot. The various libraries listed in Table 1 are utilized in the software.

Library	**Use**	**URL**
DigitalTxRXPi	Open source C language library for the Digital Transceiver for the Raspberry Pi board that controls the AX5043 chip, written by Jonathan Brandenburg of Brandenburg Tech.	[5]
WiringPi	Open source C library for GPIO, SPI, and I2C bus access on the Raspberry Pi	[6]
MoPower	Python 3 library that communicates between the Raspberry Pi and the MoPower UPS v2 board	[3]

Table 1. Software Libraries used in Raspberry Pi

B. MoPower UPS V2 Board

This board provides Uninterruptable Power Supply functionality to a Raspberry Pi by providing battery power via the GPIO interface. This particular board was chosen because of the telemetry functionality built-in. A key function of the board is battery charging and management of the Nickel Metal Hydride (NiMH) batteries. A 15 V AC/DC powerpack is the primary battery charger, with the solar panels, through the Solar Power Management board as secondary. NiMH batteries were chosen to avoid the shipping and packaging requirements needed for Lithium-ion batteries. For classroom and experiment modes, a 200 mAh 9 V NiMH battery will used so that charging and discharging voltage changes can be seen in real-time. Also, this makes it easier to show the automatic shutdown after a period of eclipse. For extended demonstrations and display at events such as hamfests, a bank of six 800 mAh AAA or 2500 mAh AA NiMH batteries can be used to give many hours of operation.

The UPS board has a built-in microcontroller which monitors battery and charging voltages and currents, and communicates with the Raspberry Pi through the GPIO UART (Universal Asynchronous Receiver/Transmitter) using a simple 19.2kb/s text interface. Note that the Bluetooth interface must

be disabled or the clock rate changes when the UART is enabled, making the Digital Transceiver board unreachable. The Raspberry Pi runs Python 3 code that communicates with the board and safely shuts down the Raspberry Pi when the battery voltage drops below 7 V. This avoids file corruption on the SD card that is common if the Pi loses power suddenly.

A momentary push button switch is also provided to reboot (press) or shutdown or startup (press and hold for 5 seconds) the Pi. The microcontroller can also be programmed for certain events. We use this functionality to automatically shutdown the Pi after an extended period of eclipse, and to start up the Pi from a shutdown state when the RBF pin is removed and the solar panels are illuminated for a period of time. In addition, the MoPower board has four 10-bit analog inputs (0 – 1.1 V) which could be used to gather additional telemetry information from sensors in the future.

C. Digital Transceiver for the Raspberry Pi Board

The Digital Transceiver for the Raspberry Pi board is a transmitter/receiver for various digital modulation schemes based on the AX5043 chip. The board is produced by Brandenburg Tech [7]. The drivers and API library are available on GitHub [5].

The board supports both the I2C (Inter-Integrated Circuit) interface and the SPI (Serial Peripheral Interface) but only the SPI interface is used in the current code. The board supports a wide range of data rates and modulation schemes. In the initial proof of concept prototype, two modes are utilized: CW (Continuous Wave, i.e. Morse code, also known as On-Off Keying or OOK) and 1200 bps AFSK (Audio Frequency Shift Keying) with X.25 packet formatting. The transmitter is configured to use the 70cm amateur radio band.

D. Solar Power Management Board

Power to the CubeSat in flight mode is provided by the batteries and the solar panels. For the 1U model, five 65mm by 65 mm 5.5 V 110 mA panels are used, mounted on the +X, -X, +Y, -Y, and +Z sides. For the model with solar panel wings, two 160 mm x 70 mm 7.2 V 200 mA panels are mounted on the wings. Under room illumination, minimal power is delivered by the solar panels; however, a 250 W halogen work lamp placed about 10cm away produces about half the rated power for indoor usage. Placing the CubeSat Simulator on a small motorized turntable spinning at around 4 r.p.m. next to a work lamp can simulate a CubeSat rotating in the sun.

On the +Z side (top) of the CubeSat Sim, there are a number of controls and switches and a quarter-wave antenna that connects via a 90-degree adapter and an SMA cable to the Digital Transceiver board. A barrel jack, 5.5 mm x 2.1 mm center positive, is provided for charging the NiMH batteries with 12 - 15 V DC input, such as from an AC power pack. The Remove Before Flight (RBF) pin switch is implemented as a 3.5 mm TRRS (Tip Ring Ring Sleeve) plug and jack. To switch the source of power between the DC jack and the solar panels, we use the two switches in the jack that are open when a 3.5 mm plug is plugged in, and closed when the plug is unplugged. When plugged in, the input power to the MoPower UPS is the DC Power Input jack. When unplugged, the input power to the MoPower UPS is the output of the Solar Power Management board. The push button switch is wired to SW3 on the MoPower board, and is used to reboot, shutdown, and startup the CubeSat Sim.

Each solar panel on the CubeSat Sim is connected together through a 1N5817 Schottky barrier diode rated at 20 V and 1 A to prevent reverse current flow. The 1N5817 was chosen for its low forward

voltage drop of about 0.45 V. Each panel's current and voltage is monitored using an Adafruit INA217 board that uses the I2C bus (Inter-Integrated Circuit, pronounced I-squared-C) to communicate with the Raspberry Pi. The Raspberry Pi has two I2C buses, available on the GPIO interface, in which the Pi acts as the bus master. A DC-DC Adjustable step-up power converter module [8], based on the ML6009 chip, acts as a boost converter circuit, to increase the 5.5 V from the solar panels to 15 V needed for the MoPower board to charge the NiMH batteries.

E. Ground Station

The ground station can be any radio receiver capable of receiving FM and CW on the 70cm band. Since a PC is required to decode the telemetry, a great option is to use a Software Defined Radio (SDR) dongle such as an RTL-SDR [9] ($20 on Amazon.com) or the FUNcube Dongle made by AMSAT-UK [10] and a PC. Any SDR software could be used including the freeware SDR# (pronounced SDR sharp) [11] or HDSDR [12], or the open source Gqrx [13]. Figures 4 and 5 show SDR# tuning the CW and AFSK telemetry.

Other software is needed to decode the telemetry information. For the CW telemetry, there are various decoding programs. For the AFSK, the open source Qtmm AFSK 1200 [14] works well. Note that some kind of speaker-to-microphone audio patching software is needed to pipe the audio output from the SDR software into the microphone input of the decoding software. For Windows, we have used VB-CABLE Virtual Audio Device, which is licensed as donationware [15]. The raw telemetry is then copy and pasted into a spreadsheet to decode and display the actual telemetry values. For fun, we chose the AO-7 telemetry format (e.g. hihi 1aa 1bb 1cc 1dd 2ee … where aa, bb, cc, and dd are two decimal digits that encode channel 1 data, etc,). Other formats can be added in the future, providing "emulation" for other satellites.

Note that the spreadsheet that we use is a modification of the actual "Morse Code Telemetry Frame Decoder for AMSAT-OSCAR-7" by Jan King, W3GEY, and Jim White, WD0E, as shown in Figure 6. Formulas added to the spreadsheet take pasted telemetry frames and separates (parses) them into channels for display, which are then decoded into actual values. Most of the telemetry values in the AO-7 format are used by the CubeSat Simulator.

This ground station option requires the installation of SDR dongle drivers on a user's PC, which is a manual process. There are some possible ways to avoid doing this. One would be to use a Raspberry Pi 3B or 3B+ with either a Digital Transceiver for the Raspberry Pi board configured to act as a receiver, or a Pi with an RTL-SDR dongle. This Raspberry Pi could be used directly with a monitor, keyboard and mouse, or it could be accessed via a PC using a VNC connection over a network, or a direct USB serial connection. Another interesting variant would be to build a ground station with a Linux Wi-Fi router (such as an old Linksys) running a rtl_tcp server [17] with an RTL-SDR dongle. The rtl_tcp server software allows any PC connected to the Wi-Fi network to connect to the RTL-SDR radio using SDR# and receive the IQ (In-phase and Quadrature) data in a stream which they can then demodulate and decode on their own PC. This would also have the advantage of a Wi-Fi network that the CubeSat Sim would always connect to, making access and configuration easy. Plugging in the Ethernet of the Linux Wi-Fi router to the internet would allow software updates and even remote access to the CubeSat Sim. This same approach that allows users of SDR# to connect to the server and demodulate and decode on their own PC could allow multiple participants in a room to do this, or even for remote participants on a web conference, for example, if the network access was properly configured.

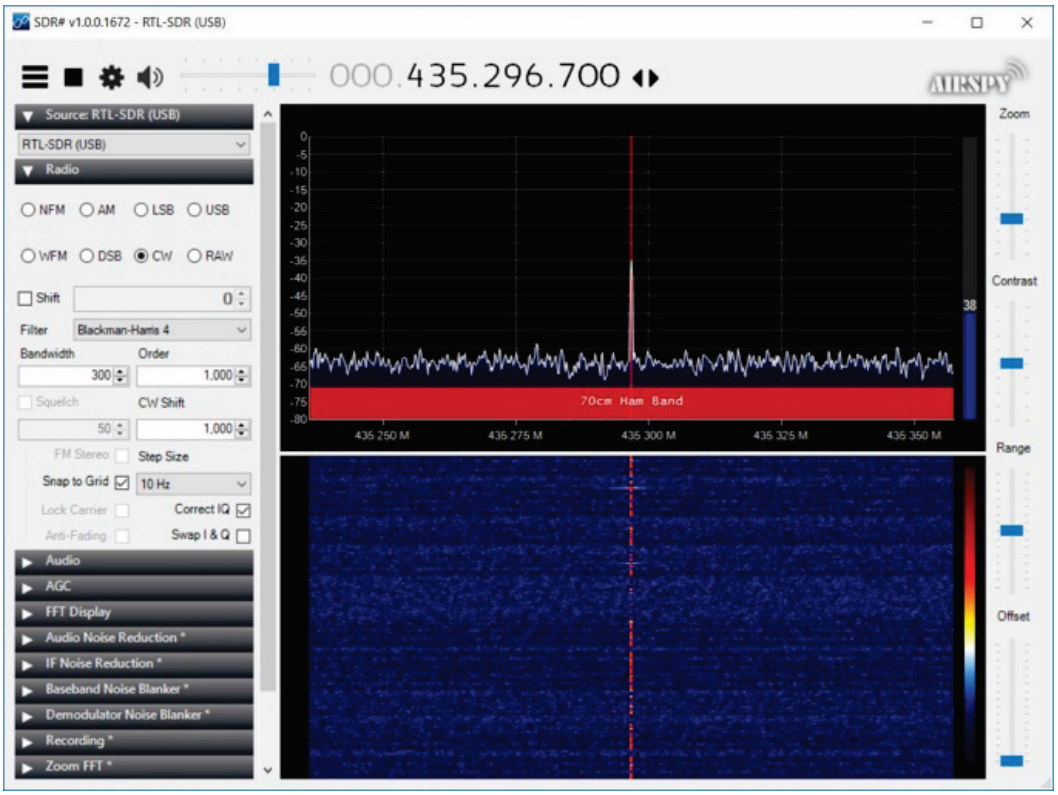


Figure 4. SDR# Decoding CW Telemetry.

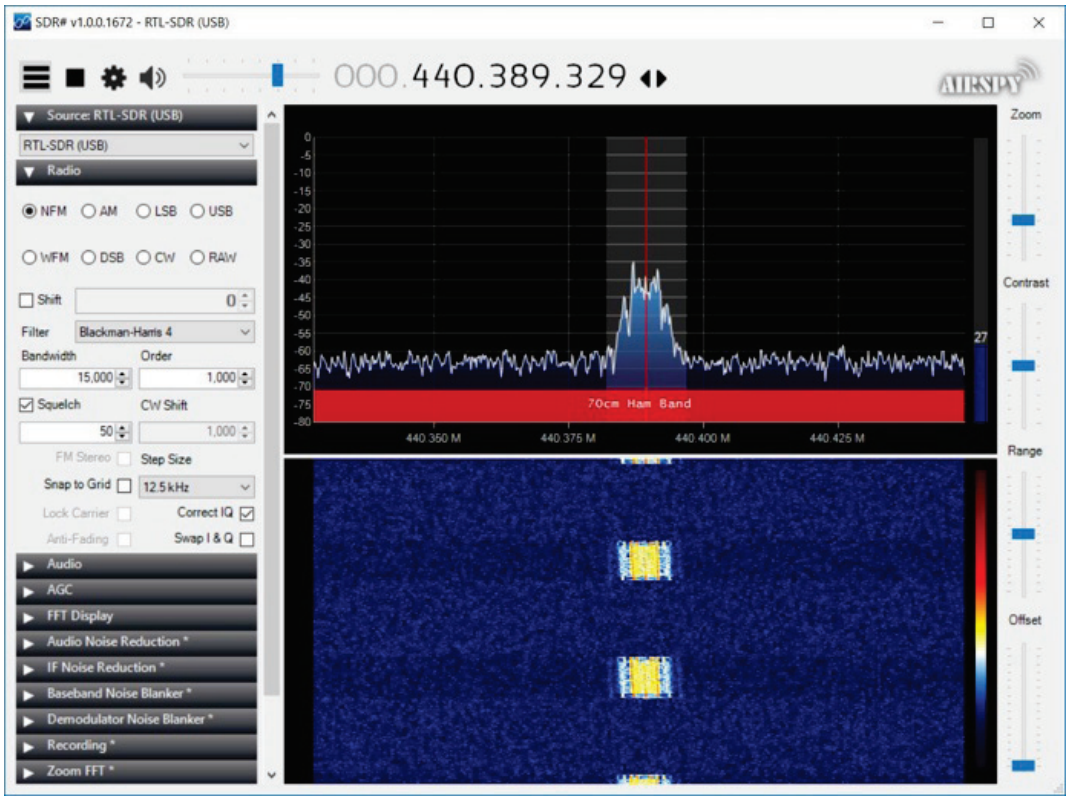
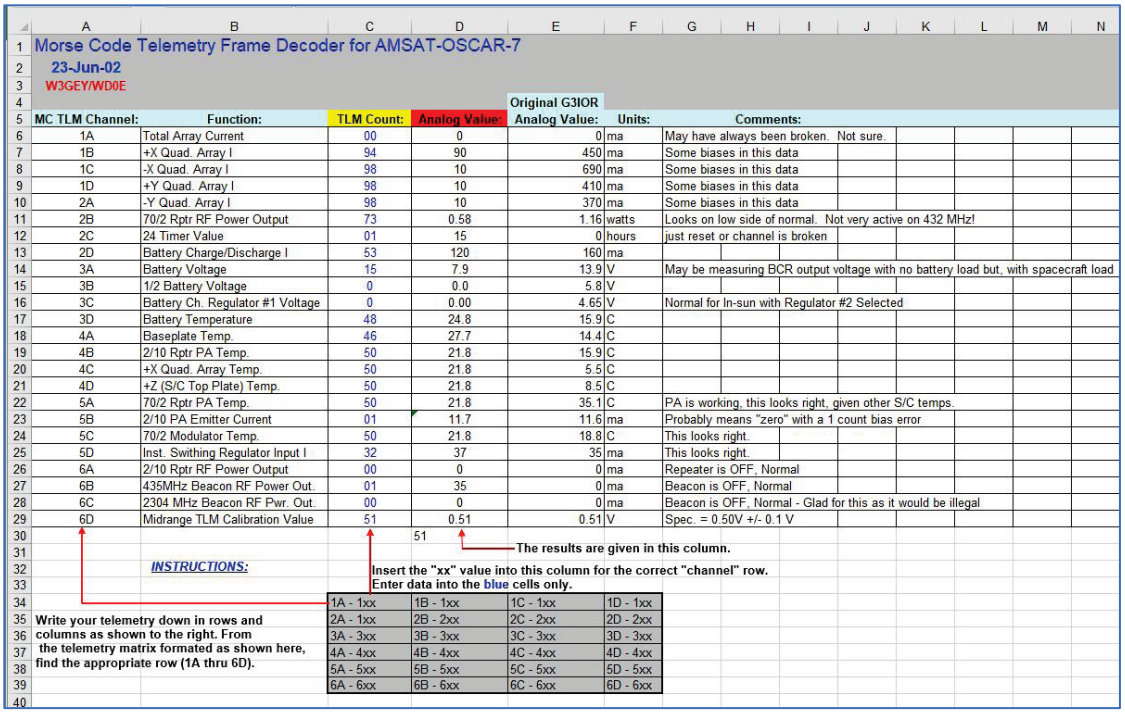


Figure 5. SDR# Decoding 1200 bps AFSK X.25 Telemetry.



Morse Code Telemetry Frame Decoder for AMSAT-OSCAR-7

23-Jun-02

W3GEY/WD0E

MC TLM Channel:	Function:	TLM Count:	Analog Value:	Original G3IOR Analog Value:	Units:	Comments:
1A	Total Array Current	00	0	0	ma	May have always been broken. Not sure.
1B	+X Quad. Array I	94	90	450	ma	Some biases in this data
1C	-X Quad. Array I	98	10	690	ma	Some biases in this data
1D	+Y Quad. Array I	98	10	410	ma	Some biases in this data
2A	-Y Quad. Array I	98	10	370	ma	Some biases in this data
2B	70/2 Rptr RF Power Output	73	0.58	1.16	watts	Looks on low side of normal. Not very active on 432 MHz!
2C	24 Timer Value	01	15	0	hours	just reset or channel is broken
2D	Battery Charge/Discharge I	53	120	160	ma	
3A	Battery Voltage	15	7.9	13.9	V	May be measuring BCR output voltage with no battery load but, with spacecraft load
3B	1/2 Battery Voltage	0	0.0	5.8	V	
3C	Battery Ch. Regulator #1 Voltage	0	0.00	4.65	V	Normal for In-sun with Regulator #2 Selected
3D	Battery Temperature	48	24.8	15.9	C	
4A	Baseplate Temp.	46	27.7	14.4	C	
4B	2/10 Rptr PA Temp.	50	21.8	15.9	C	
4C	+X Quad. Array Temp.	50	21.8	5.5	C	
4D	+Z (S/C Top Plate) Temp.	50	21.8	8.5	C	
5A	70/2 Rptr PA Temp.	50	21.8	35.1	C	PA is working, this looks right, given other S/C temps.
5B	2/10 PA Emitter Current	01	11.7	11.6	ma	Probably means "zero" with a 1 count bias error
5C	70/2 Modulator Temp.	50	21.8	18.8	C	This looks right.
5D	Inst. Swithing Regulator Input I	32	37	35	ma	This looks right.
6A	2/10 Rptr RF Power Output	00	0	0	ma	Repeater is OFF, Normal
6B	435MHz Beacon RF Power Out.	01	35	0	ma	Beacon is OFF, Normal
6C	2304 MHz Beacon RF Pwr. Out.	00	0	0	ma	Beacon is OFF, Normal - Glad for this as it would be illegal
6D	Midrange TLM Calibration Value	51	0.51	0.51	V	Spec. = 0.50V +/- 0.1 V

51

The results are given in this column.

INSTRUCTIONS:

Insert the "xx" value into this column for the correct "channel" row.
Enter data into the blue cells only.

Write your telemetry down in rows and columns as shown to the right. From the telemetry matrix formated as shown here, find the appropriate row (1A thru 6D).

1A - 1xx	1B - 1xx	1C - 1xx	1D - 1xx
2A - 1xx	2B - 2xx	2C - 2xx	2D - 2xx
3A - 3xx	3B - 3xx	3C - 3xx	3D - 3xx
4A - 4xx	4B - 4xx	4C - 4xx	4D - 4xx
5A - 5xx	5B - 5xx	5C - 5xx	5D - 5xx
6A - 6xx	6B - 6xx	6C - 6xx	6D - 6xx

Figure 6. Morse Code Telemetry Frame Decoder for AMSAT-OSCAR-7 Spreadsheet with CubeSat Simulator Data

F. CubeSat Simulator Frame

This proof of concept prototype has concentrated on functionality, with form taking a lower priority. Also, as electrical engineers, we have stayed in our comfort zone of electronics and software rather than spending a lot of time and energy on the physical design.

We have produced two frames to house the board stack. One is based around 3D printed 1U CubeSat parts from the website Thingverse [16]. Fully threaded 3 mm steel rods were used as the structure, and clear plexiglass shelves and panels were used for mounting boards and solar panels. The Raspberry Pi stack was housed in this frame, and is shown in Figure 7 below.

Figure 8 shows a frame using the original ETP CubeSat Simulator sheet metal boxes with “wings” for the solar panels.

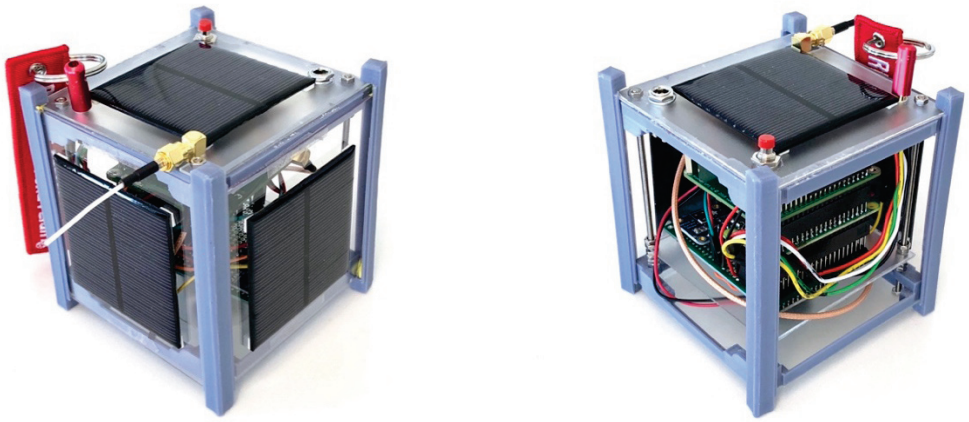


Figure 7. CubeSat Simulator 1U Frame using 3D Printed Parts.

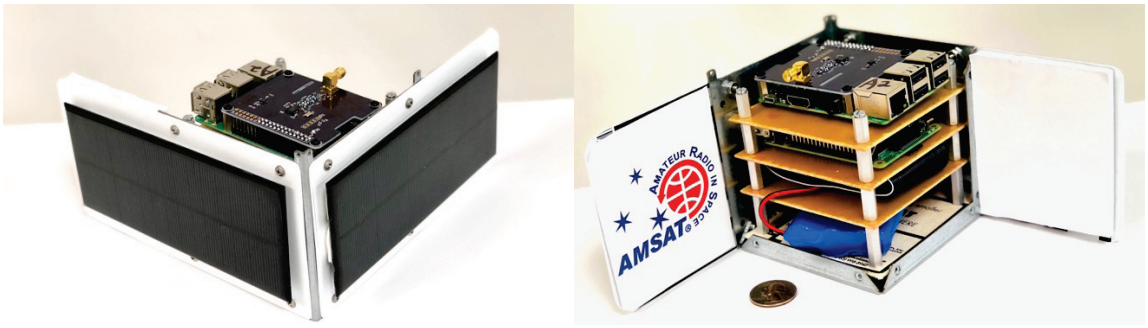


Figure 8. CubeSat Simulator Winged Frame using Original ETP CubeSat Simulator Sheet Metal Frame.

G. Cost

The approximate cost of making the CubeSat Sim is shown in Table 2.

Part	**Qty**	**Cost**	**Total**
Digital Transceiver for the Raspberry Pi board	1	$60.00	$60.00
MoPower V2 UPS board for Pi	1	$60.00	$60.00
Adafruit INA219 DC current/voltage sensor board	5	$10.00	$50.00
Solar Cells, 5.5 V,110 mA 65 mm x 65 mm	5	$5.00	$25.00
Raspberry Pi Zero W CPU	1	$20.00	$20.00
RTL-SDR USB dongle for PC	1	$20.00	$20.00
16 GB SD Card with Raspbian Stretch	1	$18.00	$18.00
AC/DC power adapter 15 V	1	$13.00	$13.00
Clear acrylic sheet 8 x 10	2	$5.00	$10.00
SMA M-M Cable	1	$7.00	$7.00
SMA Cable M-F	1	$6.00	$6.00
2x40 pin stackable header	2	$2.75	$5.50
SMA Antenna 433 MHz	1	$5.00	$5.00
9 V NiMH battery	1	$5.00	$5.00
Various hardware	1	$5.00	$5.00
TRRS plug and jack for RBF switch	1	$5.00	$5.00
SMA 90 degree M-F	1	$3.00	$3.00
1N5817 Schottky diode	5	$0.45	$2.25
DC-DC Boost Converter Module XL6009	1	$2.00	$2.00
Momentary pushbutton switch	1	$1.50	$1.50
Barrel Jack for AC/DC charger	1	$0.75	$0.75
TOTAL			**$324.00**

Table 2. Cost of Components for the Prototype.

V. Applications and Uses of the CubeSat Simulator

Various educational exercises with a CubeSat Simulator are described in Mark Spencer's paper [18]. This new CubeSat Sim can be used in many of these exercises. In addition, we anticipate that the CubeSat Simulator will be useful to teams planning to build a CubeSat to gain experience. Also, we hope that emulation for additional satellites will provide practice and training in copying telemetry from new and existing satellites in a classroom setting. We plan to write an article in the AMSAT Journal describing activities and exercises with the CubeSat Simulator.

There is one interesting way in which users without an RTL-SDR radio and antenna can participate in demos using only an internet connected PC. If a remotely accessible SDR server is receiving the CubeSat Simulator transmissions, other users can connect to the server and then do their own decoding of the telemetry. For example, the rtl_tcp [17] server software that allows users of SDR# to connect to the server and demodulate and decode on their own PC could allow multiple participants in a room to do this, or even for remote participants on a web conference, for example, if the network access was properly configured.

Currently, the CubeSat Sim supports two telemetry modulation schemes: CW and 1200 bps AFSK X.25. In both cases, the telemetry is formatted in AO-7 format. In the future, support for additional telemetry modulation schemes and telemetry formats can be added. One interesting thing to do in the future would be to implement the Data Under Voice (DUV) 200 bps FSK telemetry used by the AMSAT Fox satellites. This "Fox emulation mode" would allow the use of the FoxTelem software to decode the telemetry. Also, in the future, developers of a new CubeSat could contribute an emulation mode for an upcoming satellite. This would allow amateurs to practice decoding telemetry and using the telemetry analysis tools before launch, avoiding the scramble after a CubeSat is launched and potential loss of initial telemetry data. At AMSAT, we can also ensure that we provide a "GOLF emulation mode" as our next generation of satellites are developed, providing excitement and training on telemetry reception prior to launch.

VI. Next Steps

Our next steps are to get community feedback on the design and implementation. We are particularly looking for improvements for the frame, to make it sturdy and easy to build.

We plan to fully document hardware and software online and in the AMSAT Journal so that others can build their own. We are also looking for Beta testers to test it out in public demonstrations and classroom exercises and provide feedback. Please contact us directly if you are interested. Teachers are encouraged to write and share example Lesson Plans at specific age and grade-appropriate levels to help educators incorporate the simulator in classes and extracurricular activities.

AMSAT also plans to build a number of AMSAT owned CubeSat Simulators and make them available to educators to use by shipping them around. To support this, we will document presentations and activities to be used with the CubeSat Sim. Ultimately, we hope to grow a community of satellite simulator enthusiasts who continue to improve and extend the CubeSat Sim, adding additional functionality and satellite emulation modes.

VII. Acknowledgments

The authors would like to thank Jonathan Brandenburg for his help and assistance. His timely technical support on the Brandenburg Tech Digital Transceiver for the Raspberry Pi Board has been invaluable. Thanks to Mark Spencer for his aforementioned trailblazing work, and to Bob Bruninga for ideas and inspiration from his undergrad "LabSat" developments.

We would also like to acknowledge all the open source hardware and software that is a part of the AMSAT CubeSat Simulator.

Finally, we would like to acknowledge the support of the AMSAT Board of Directors and AMSAT President Joe Spier for their support and encouragement of this project.

VIII. References

[1] The AMSAT Journal article "Education With A Satellite Simulator: ETP CubeSat Simulator," by Mark Spencer, ARRL Education and Technology Program Coordinator, Part 1 in the September/October 2009 issue http://www.arrl.org/files/file/ETP/CubeSat/CubeSat-Pt1-SepOct09.pdf

[2] https://www.raspberrypi.org/products/raspberry-pi-zero-w/

[3] http://www.allspectrum.com/mopower/

[4] https://github.com/alanbjohnston/CubeSatSim

[5] https://github.com/BrandenburgTech/DigitalTxRxRPi

[6] http://wiringpi.com/

[7] https://brandenburgtech.wordpress.com

[8] https://www.amazon.com/gp/product/B06XWSV89D

[9] https://www.rtl-sdr.com

[10] https://amsat-uk.org/funcube/funcube-dongle-sdr/

[11] https://airspy.com/download/

[12] http://www.hdsdr.de/

[13] http://gqrx.dk/

[14] https://sourceforge.net/projects/qtmm/

[15] https://www.vb-audio.com/Cable/

[16] https://www.thingiverse.com/thing:27300

[17] https://osmocom.org/projects/rtl-sdr/wiki/Rtl-sdr#rtl_tcp

[18] The AMSAT Journal article "Education With A Satellite Simulator: ETP CubeSat Simulator," by Mark Spencer, ARRL Education and Technology Program Coordinator, Part 2, in the November/December 2009 issue, http://www.arrl.org/files/file/ETP/CubeSat/CubeSat-Pt2-NovDec09.pdf

ARISS InterOperable Radio System (IORS)

Lou McFadin W5DID, Ken Ernandes N2WWD, and Dave Taylor W8AAS

INTRODUCTION

The Amateur Radio on the International Space Station (ARISS) team plans to fly the IORS as a vital segment of the ARISS payload. This equipment will be interfaced with other ARISS payload hardware and used on the International Space Station (ISS) to support the National Aeronautics and Space Administration (NASA) and other space agencies in space agency outreach, educational outreach, backup communication and experimentation. The ARISS IORS consists of a suite of amateur radio equipment and is designed to be interoperable. In other words, it is designed to be employed in both the US Operating Segment and the Russian Operating Segment using either the 28 VDC or 120 VDC ISS power system. The IORS consists of a Kenwood D710GA amateur radio transceiver mounted to the Multi-Voltage Power Supply (MVPS), and the associated interconnecting cabling.

Objectives of upcoming changes to the ARISS equipment on the ISS will:

- Improve the Columbus Module downlink signal reception through a higher power radio.
- Enhance ARISS capabilities for educational contacts, every-day amateur use, and ISS backup communications
- Develop standardized VHF/UHF radio and power supply system that will be interoperable across all ISS Segments and modules including both the US and Russian segments.
- Certify, launch, install and operate a JVC Kenwood system with an ARISS/AMSAT-built interoperable power supply and supporting cabling.

Mission Overview

ARISS is a long-running program using amateur radio equipment on board the International Space Station to involve students exchanging questions with astronauts on orbit. More than 1000 organizations have participated since the payload was first turned on in November 2000. Organizations include schools, museums, scouting events, and special events. It is also used to perform communications experiments with amateur radio operators on the ground. NASA's intent in having astronauts take part in ARISS is to involve the largest possible number of people, particularly youth, in Science, Technology, Engineering, Arts, and Math (STEAM) education in conjunction with the US, Russian, European, Canadian and Japanese space programs and through the help of amateur radio operators around the world. ARISS also serves an important function as a tertiary backup in the event of communications outages on the US and Russian sides.

Through ARISS, astronauts make scheduled and unscheduled Amateur Radio contacts with schools, random contacts with Amateur Radio operators, and contacts with astronauts' families. A few schools are selected from around the world for scheduled contacts with the ISS crew, after completing a comprehensive proposal that indicates a plan most consistent with ARISS educational goals. Scheduled contacts give the schools a 95% chance at achieving success. Ten or more students at each school ask the astronaut questions. The nature of these contacts embodies the primary ARISS goal of inspiring and educating students to pursue STEAM careers.

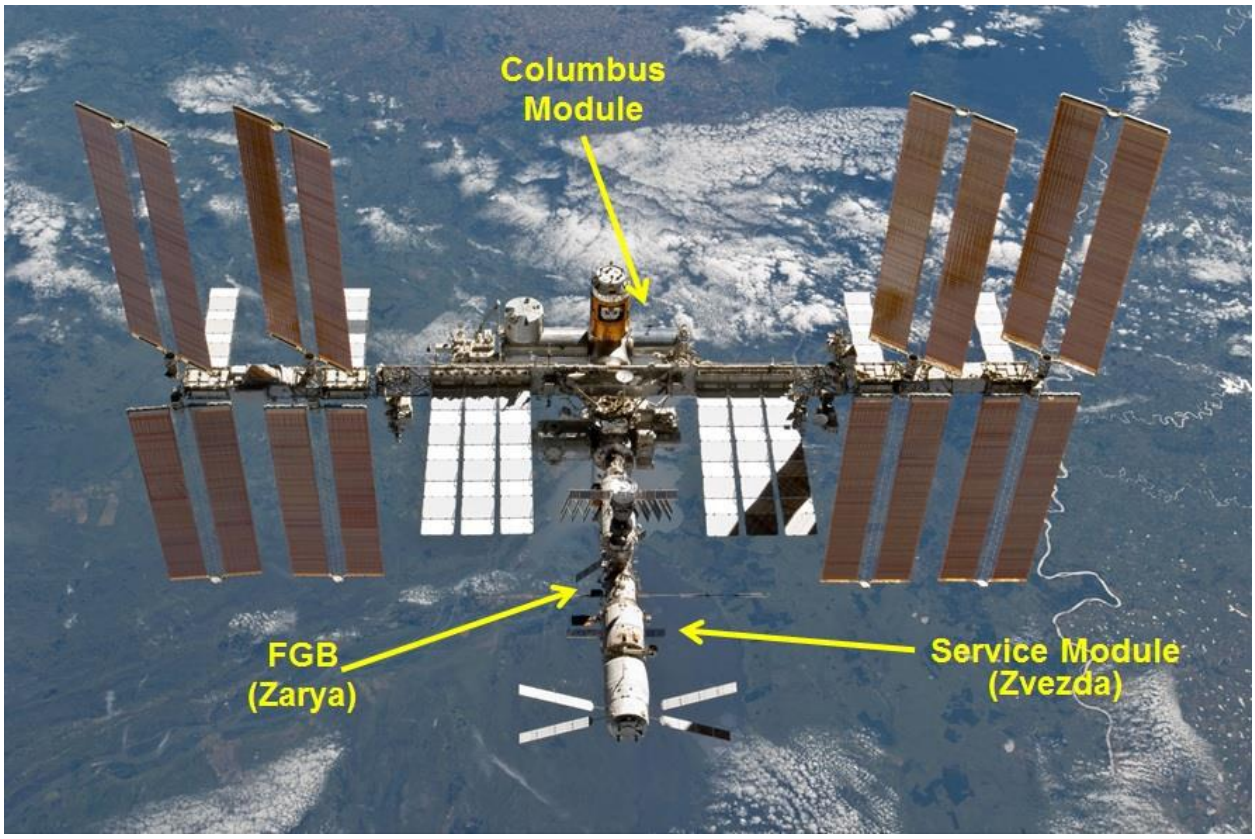
ARISS CONFIGURATION

The ARISS payload has equipment on board the ISS in the US Columbus Module and the Russian Service Module (Zvezda), with respective locations shown in figure 1. Because of the diversity of locations, the

equipment must be capable of operating from either the 120VDC or 28VDC available in US-built ISS modules, or the 28VDC available in Russian-built modules. The new IORS equipment is capable of operating on either power system and thus all equipment is interchangeable between the segments.

Equipment Deployments in ISS Modules

The IORS is an ARISS upgrade that will result in the replacement of much of the deployed ARISS legacy equipment. The key replacement components are a new [modified] JVC Kenwood D710GA radio (transceiver) with an embedded Terminal Node Controller (TNC) and a custom-designed Multi-Voltage Power Supply (MVPS). The JVC Kenwood transceiver supports voice, cross-band repeater, and digital communications modes. The MVPS provides a full set of output voltages to support IORS operation by employing either the 120VDC or 28VDC available in US-built ISS modules or the 28VDC available in Russian-built modules. The outputs include voltage pass-throughs, so that there is no loss of a power outlet when the MVPS is plugged in. The MVPS includes an integrated mounting bracket for the JVC Kenwood D710GA to



allow the radio to be mounted directly to the power supply via Velcro straps.

Figure 1, ARISS Equipment Locations on the ISS

Figure 2 shows the ARISS system configuration as installed in the Columbus Module. This installation allows the use of either the 120VDC or 28VDC power outlet. (The corresponding installation in the Service Module may only be powered by a 28 VDC outlet.) The MVPS provides power to the JVC Kenwood D710GA transceiver and (in the Columbus Module) to the Ham video system.

LEGACY ARISS EQUIPMENT

The IORS system will maintain certain legacy ARISS equipment, while replacing the key components identified. Each type of equipment will be identified as either being replaced or remaining part of the ARISS system.

Columbus Module Legacy Equipment

The Columbus module is equipped with an Ericsson handheld transceiver, an antenna assembly, a packet TNC, the Ham Video system, and associated power supplies. The transceiver, power supplies, and TNC legacy equipment will be replaced with the new IORS equipment. The Ham Video DATV system and the legacy antennas will remain in place with the IORS as the new ARISS radio system. Ham Video will be powered through the IORS Multi-Voltage Power Supply.

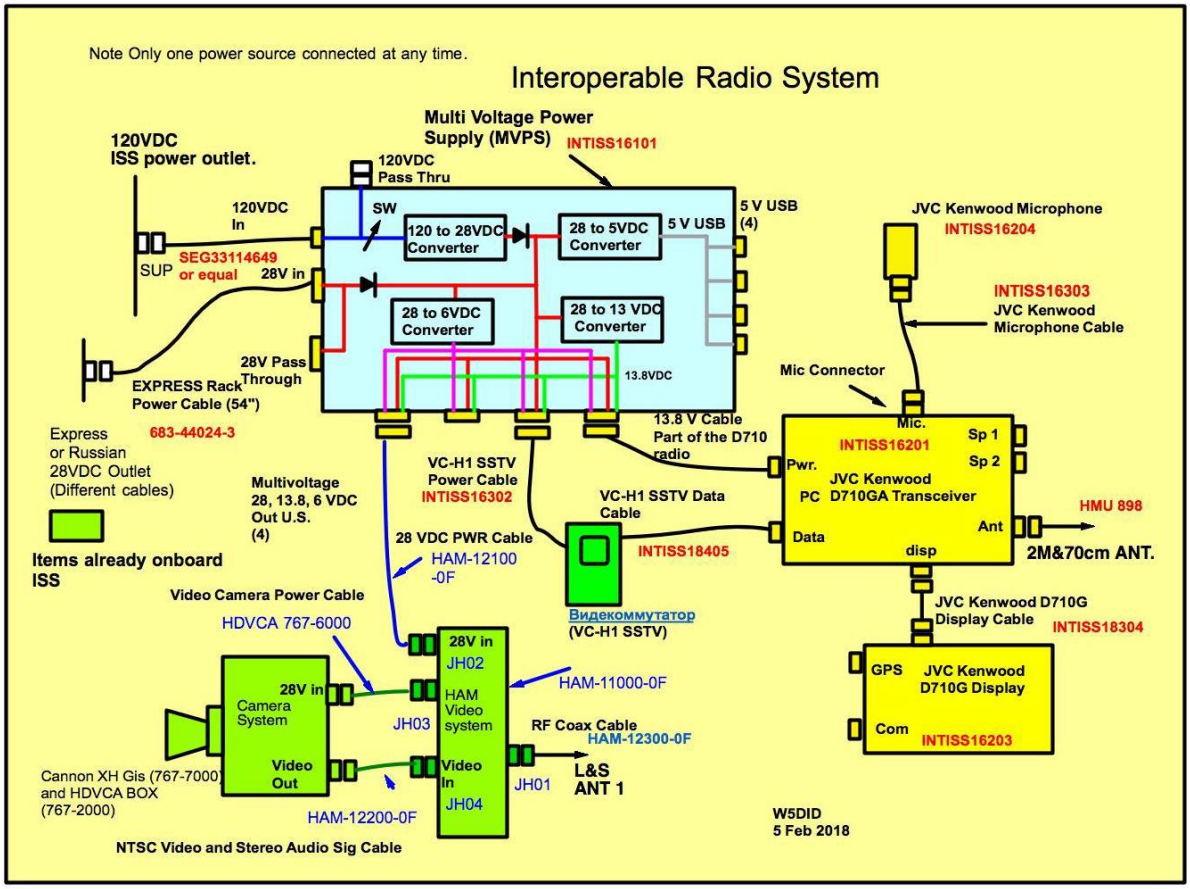


Figure 2, ARISS Columbus Module System Configuration

Columbus Module Legacy Transceiver

The Columbus Module currently has an Ericsson handheld transceiver. This transceiver is a lower power RF signal (5W) resulting in a lower level signal on the ground and a lower level audio level, when compared to the Kenwood D710 transceiver. The new IORS transceiver will thus replace the Ericsson transceiver.

Columbus Module Legacy Antennas
The Columbus module has a single externally-mounted Very High Frequency/Ultra-High Frequency (VHF/UHF) combined antenna module as well as two L-band/S-band antennas as shown in figures 3 and 4. These antennas will remain part of the ARISS configuration.

Columbus Module TNC
The Columbus Module TNC (Terminal Node Controller) is mounted inside the Packet Module Ericsson's power supply enclosure. This will be replaced with the data capability in the IORS transceiver.

Columbus Module DATV System
The Columbus Module on-board Digital Amateur Television (DATV) system is called the Ham Video system. DATV has been commissioned and the corresponding ground station network is nearing completion. This will remain in place as part of the ISS HAM system. It currently has a failure and is being sent down for repair and return ARISS system.

ARISS Radio Power Supply
The legacy ARISS Radio power supply produces 12 VDC, using a 28 VDC power source. There is a separate converter to produce 7.5 VDC needed by the Ericsson transceiver. This will be replaced with the new IORS Multi-Voltage Power Supply (MVPS).

Figure 3, Randy Bresnik installing VHF/UHF Antenna on Columbus

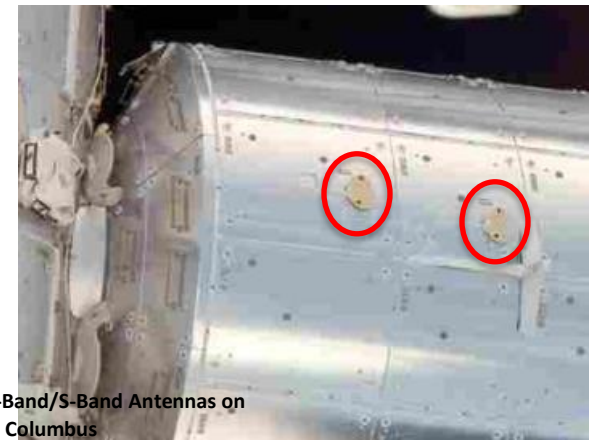


Figure 4, Two L-Band/S-Band Antennas on Columbus

Service Module Legacy Equipment
The Service module is equipped with primary and backup transceivers, an array of antennas, and two Russian 13.8VDC power supplies. The transceivers and power supply legacy equipment will be replaced with the new ARISS IORS equipment. The legacy antennas will remain in place as part of the ARISS system.

Service Module Transceivers
The Service Module has one Kenwood D710 transceiver and two D700 transceivers, only one of which is used at any time. These transceivers support ISS Ham school contacts as well as the ARISS-Russia slow-scan television operations.

Service Module Antennas

The Service Module has four externally-mounted antenna assemblies. Three of these are combined VHF/UHF antennas augmented with combined L-band / S-band patch antennas and a diplexer. The fourth antenna is a 2.5 meter length High Frequency (HF) whip (supporting 10 meter operations), also with the combined L-band / S-band microwave patch antennas and a diplexer. The microwave antenna system supports the Russian Glisser requirement, as well as amateur radio operations on L band and S band. Four dual-use antenna transmission line feedthroughs were installed on the Russian Service Module. These dual-use feedthroughs support amateur radio operations and ISS video capability and were installed during Russian and US spacewalks.

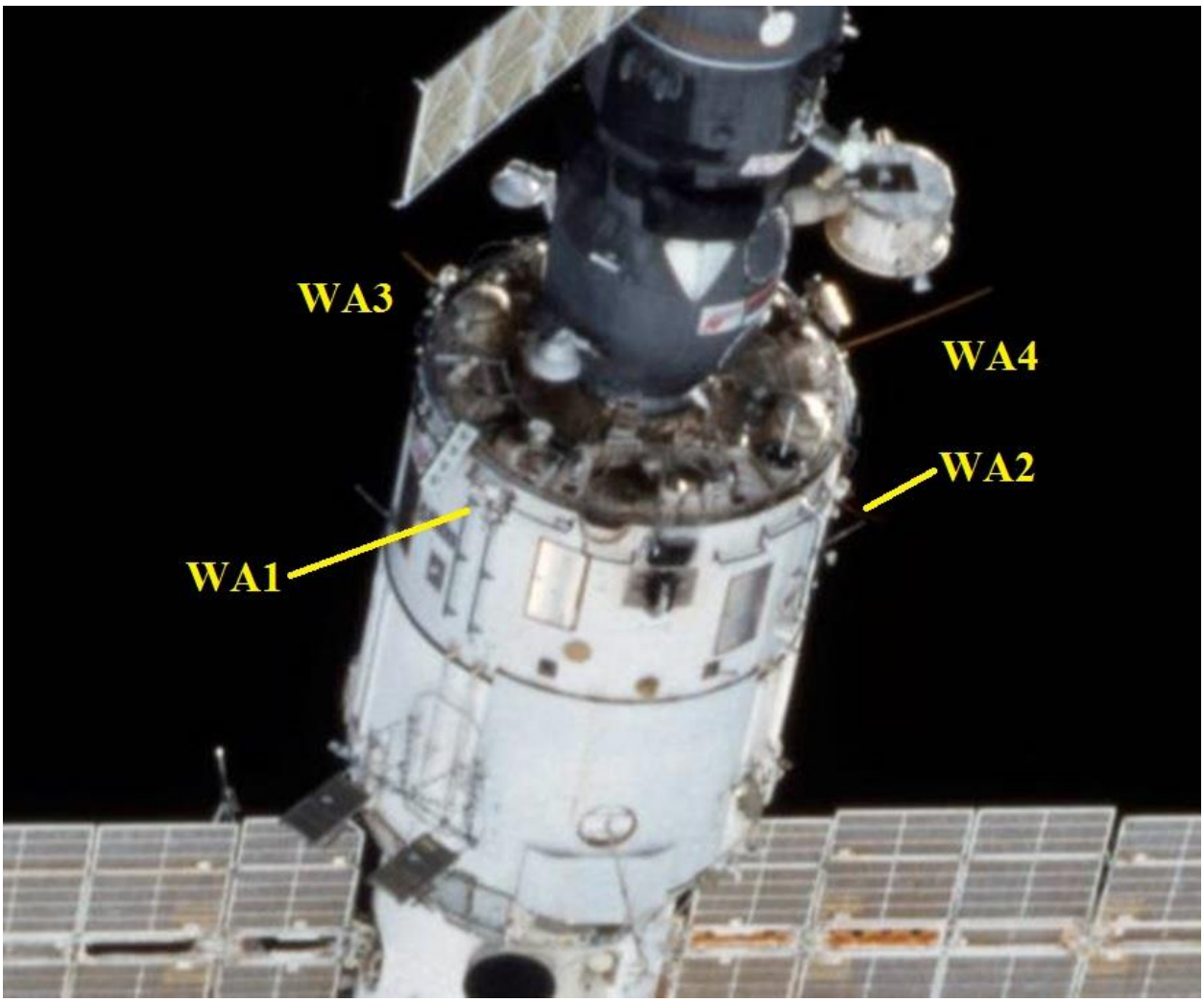


Figure 5, ARISS Antennas Mounted on Service Module

The four antenna assemblies are shown in figures 5 and 6. WA1 through WA3 (shown from the left) are VHF/UHF combined antennas (with whip elements shown encased in Kapton® tape), plus the L-band and S-band patch antennas encased in the approximately rectangular enclosure. WA4 (to the far right) is a 2.5 m HF whip antenna, also with an L-band/S-band combined antenna. The WA1 and WA2 antenna assemblies are nadir-pointing, while the WA3 and WA4 assemblies are zenith-pointing. The ARISS US and Italian teams provided the four antenna assemblies.

The microwave antenna system supports the Glisser needs at approximately 1.99 GHz as well as the amateur L and S bands and GPS and Glonass. The Italian microwave antenna is a flat spiral. This design can operate from approximately 1 GHz to about 2.4 GHz. A circular polarization requirement was imposed.

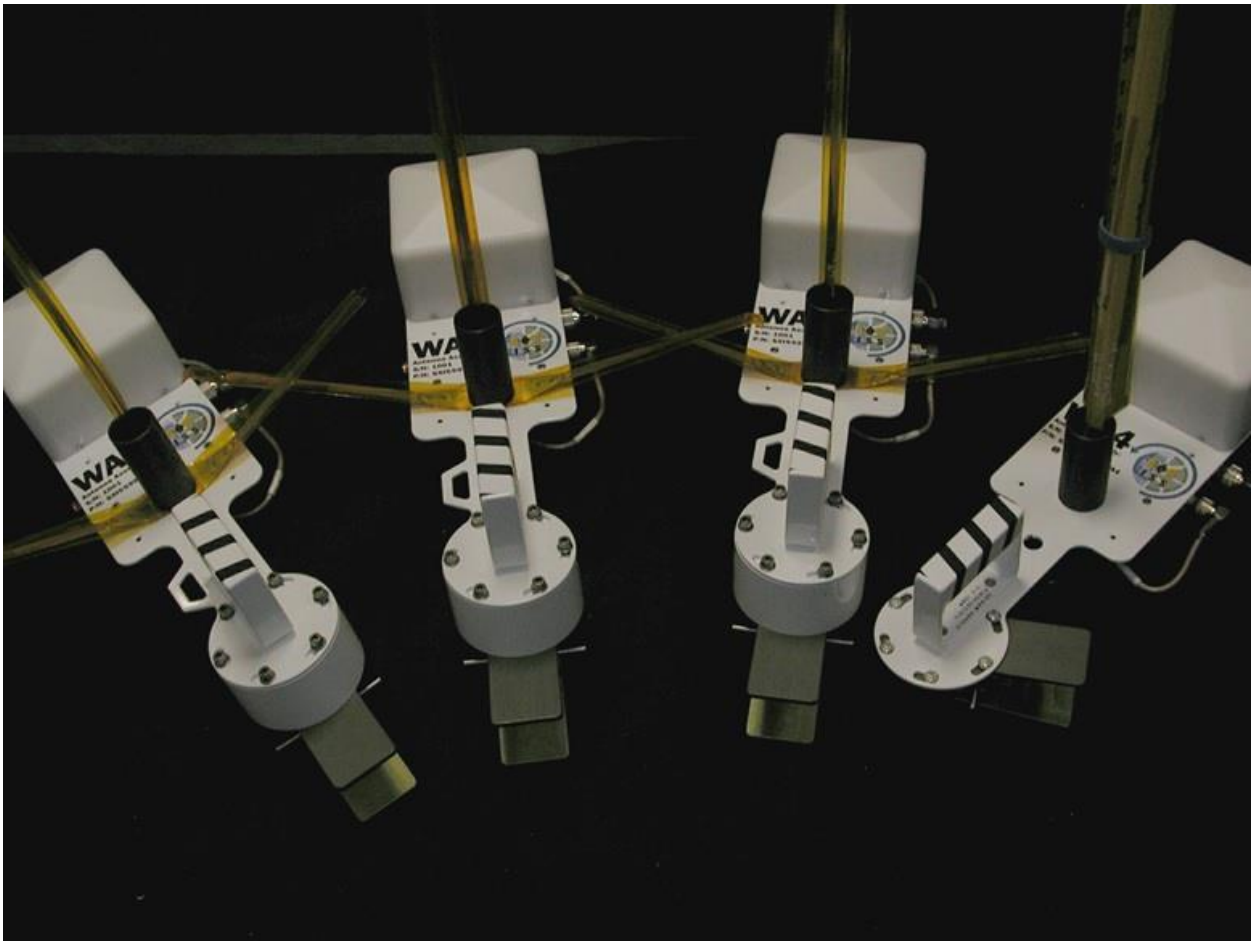


Figure 6, ARISS Service Module Antennas

Service Module Power Supply

The Service Module power is provided by two 28 VDC to 13.8 VDC power supplies. These were developed and certified by the Russian team. These will be replaced with the new IORS MVPS. The Service Module Power Supply is shown in figure 7.

Figure 7, Russian 13.8 VDC Power Supply

NEW INTEROPERABLE RADIO SYSTEM (IORS) HARDWARE

The new system enhancements:

- Higher power downlink improves school contacts, SSTV downlink and APRS operations
- Improved audio during voice contacts
- Reduced Ham TV downtime through dedicated power supply
- More robust soft/firmware in radio system to prevent accidental programming and reduce repeater mode command steps
- New JVC Kenwood D710 fan supports continuous repeater mode operations
- Sharing of hardware resources across modules when failures occur
- Common operations and training across US and Russian segments
- Supports future system developments
- Ham TV Slide Show module/dedicated camera
- IPAD SSTV operations
- Additional radio systems

The new IORS equipment consists of a JVC Kenwood D710GA transceiver, a Multi-Voltage Power Supply (MVPS), and interconnecting cables. This hardware will be interfaced with some of the legacy ARISS equipment to transmit and receive through the legacy antenna systems as shown in figure 1. The intent is to have an interoperable system with components that will be certified and can be operated anywhere on ISS, but specifically will be used in the two areas with ARISS legacy antennas: the US Columbus Module and the Russian Service Module. Interoperability provides the following advantages: it leverages existing ISS power cables, it can be moved between modules in the event of on-orbit failures, and it allows for common training and operations.

IORS Transceiver

The JVC Kenwood D710GA transceiver, shown in figure 8, is a spaceflight modified version of this commercially-available product. Figure 8 depicts its front panel and display. The key safety modifications to this transceiver are the reduction of the maximum radiated power from 50 W to 25 W (through a hardware design modification by JVC Kenwood) and installation of a more robust (higher volume) cooling fan to reduce thermal load.

IORS Power Supply

The MVPS is custom designed for the ARISS system. Figure 9 is an MVPS block diagram. The MVPS is equipped with two (2) voltage inputs, supporting 28 VDC and 120 VDC ISS power systems. The MVPS includes four (4) multi-voltage outputs, plus four (4) Universal Serial Bus (USB) power ports. Figure 10 has an assembly isometric drawing of the MVPS with the transceiver mounting bracket shown. The transceiver will be mounted in place via Velcro straps. There is one 120VDC input that supports USOS module use and one 28VDC input that supports RSOS module or USOS use. Each of the two inputs is equipped with a pass-through output in order allow further equipment to be powered from ISS power via the MVPS, without having to remove power connections to the MVPS. The MVPS includes an integrated mounting bracket that allows the Kenwood D710GA radio to be mounted directly to the power supply via Velcro straps.

Figure 8, JVC Kenwood D710G Transceiver

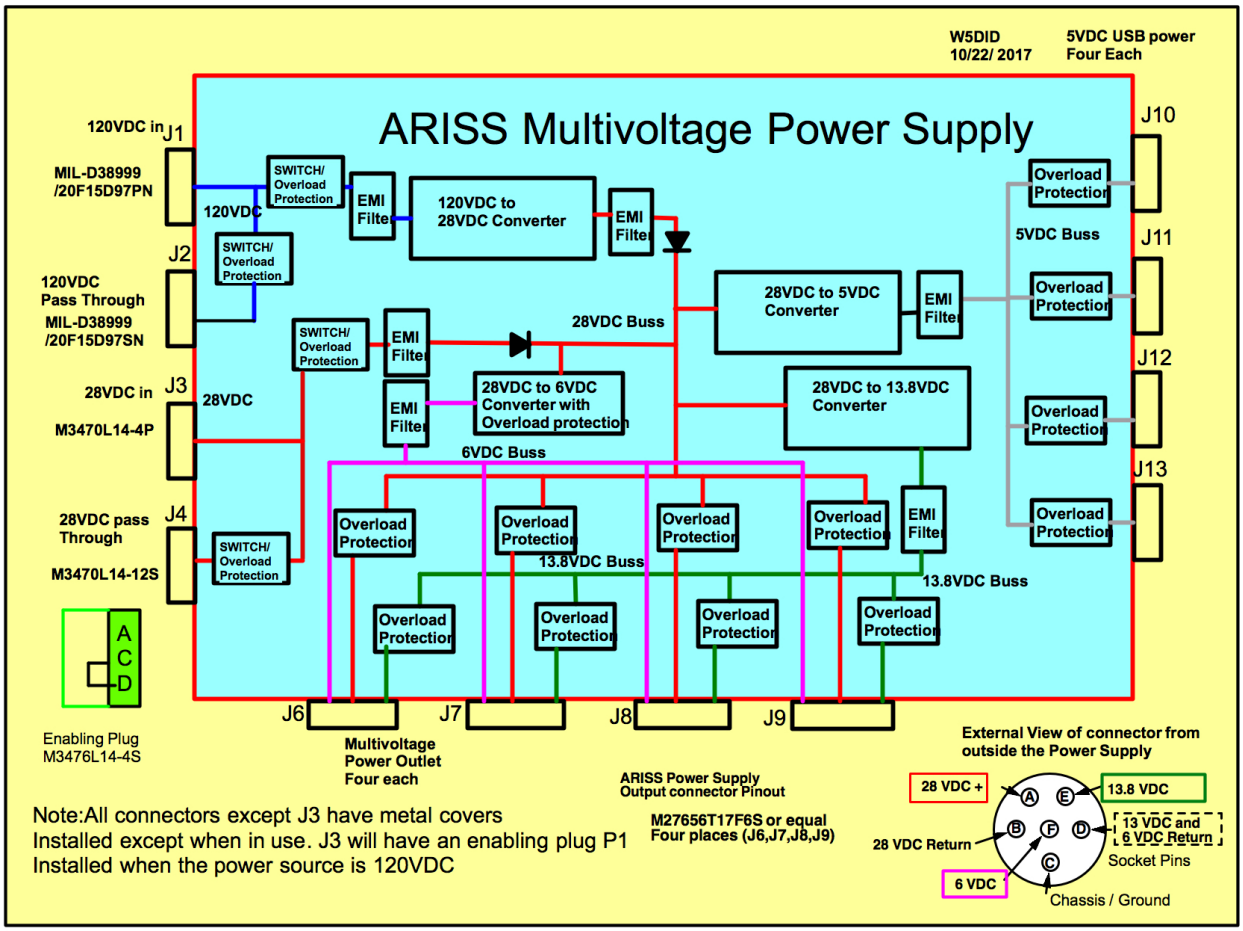


Figure 9, IORS Multi-Voltage Power Supply (MVPS)

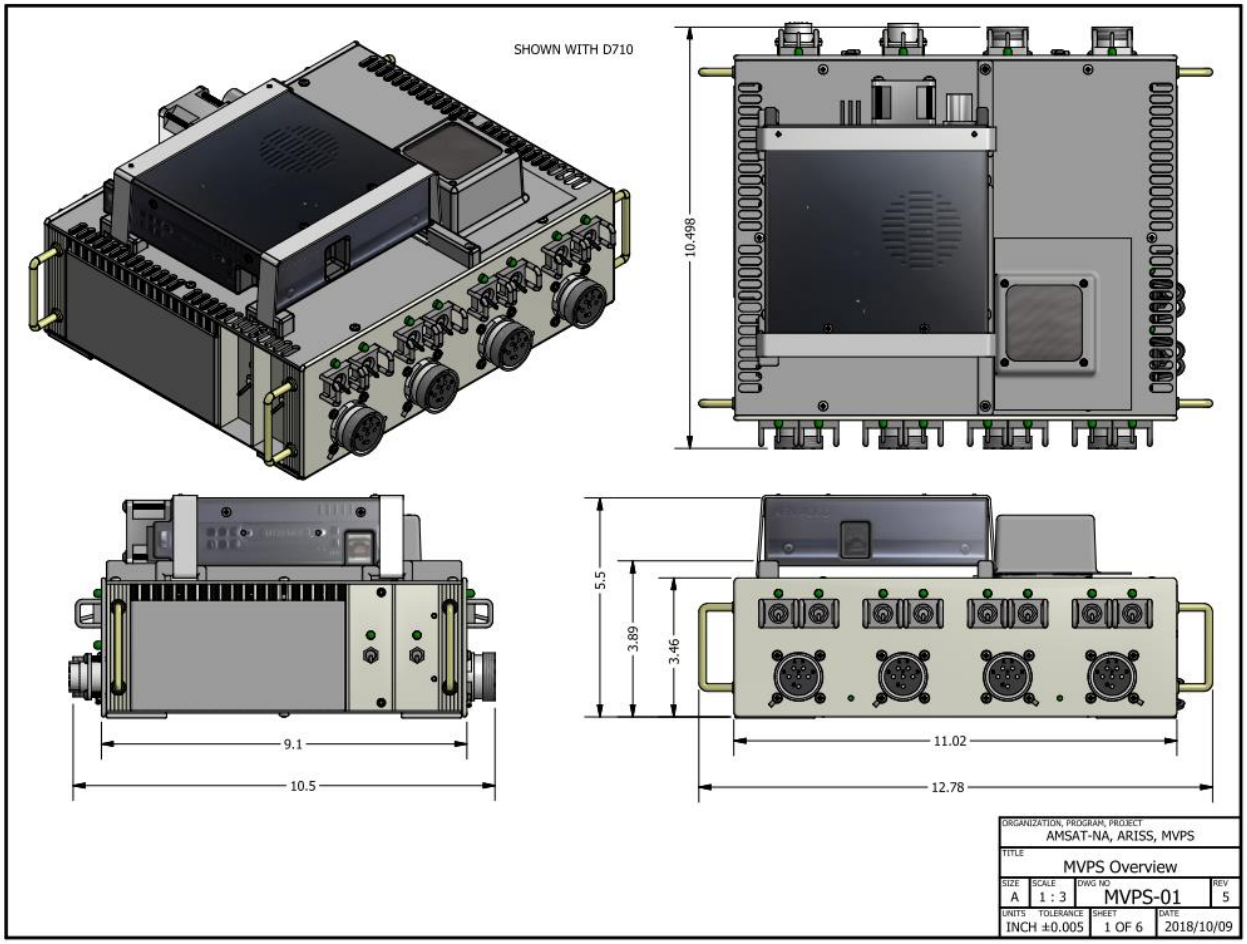


Figure 10, MVPS with JVC Kenwood D710G Transceiver Mounted

IORS OPERATING MODES

This section provides a brief description of the ARISS operating modes with the new IORS equipment installed. This is generally presented from the perspective of the ground operator. Details and updated information will be provided on the ARISS web site: http://www.ariss.org.

Voice Contacts

The ARISS system will continue to support two-way FM voice contacts pre-scheduled for schools as well as random amateur contacts. The voice downlink frequency for random contacts is **145.80 MHz** (worldwide). The voice uplink frequency is **144.49 MHz** for ITU regions 2 and 3 (the Americas, Pacific, and Southern Asia) and **145.20 MHz** for ITU region 1 (Europe, Russia, and Africa). Amateurs are cautioned not to transmit on the ISS downlink frequency. The voice contacts are split mode so the crew listens on the uplink frequency and transmits on the downlink frequency. Thus, the crew will not hear operators transmitting on the downlink frequency. The most this will accomplish is making such an operator unpopular with others monitoring the downlink and/or attempting contact.

Cross-Band Repeater Operations
The JVC Kenwood D710G transceiver is also capable of operating as a cross-band repeater. This operating mode will make the ISS an FM "easy sat" with an added bonus. The ISS crew will be able to join conversations occurring between ground stations in this repeater mode. The cross-band repeater capability was one of the drivers in the more robust thermal design in the D710G.

The uplink frequency will be in the 70 cm UHF band and the downlink frequency will be in the 2m VHF band. The actual frequencies will be available on the ARISS web site once they've been determined.

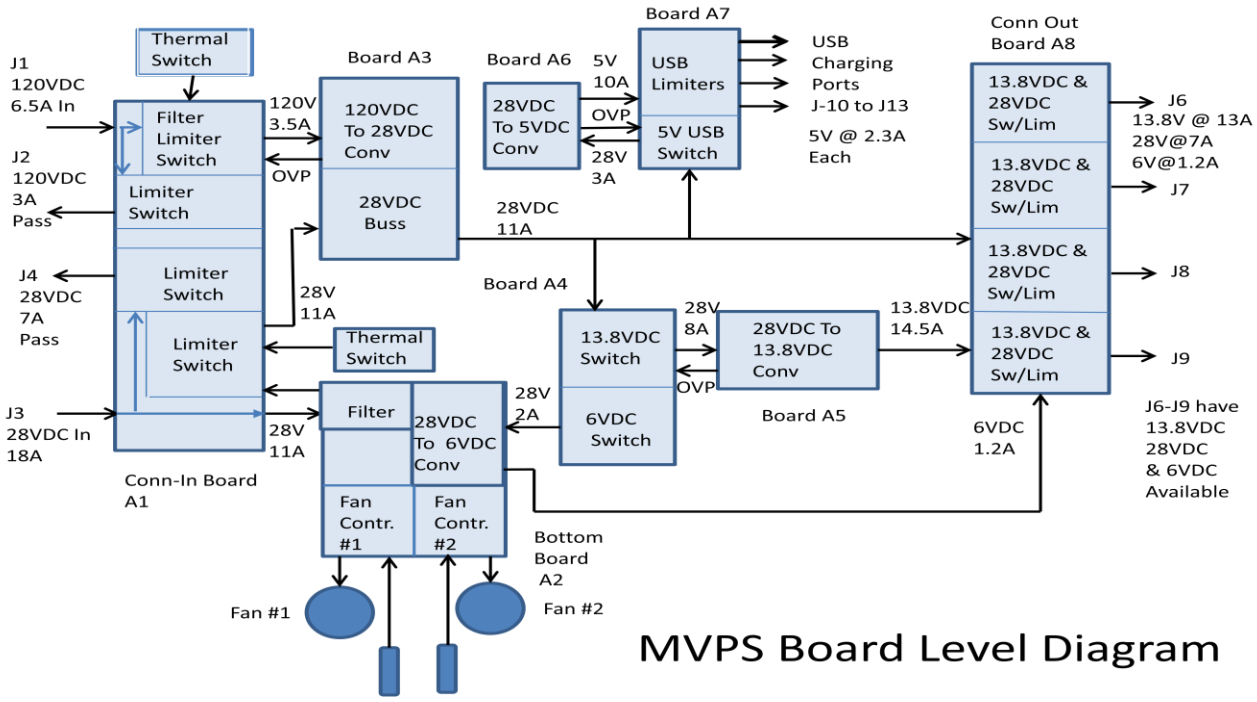
Packet Operations
Packet operations (digipeater and APRS) will be similar to those provided by the current system (Ericsson and packet module), but will take advantage of the higher output power available. The digipeater will continue to use the ARISS and APRSAT aliases. In addition – because we plan for two IORS radios on board – it will also recognize the call sign of the radio in use: NA1SS (Columbus module) or RS0ISS (Zvezda Service module).

SUMMARY
The IORS will provide a more robust amateur radio station on the ISS with some new capabilities. The most significant upgrades are the replacement of the existing transceiver, TNC, and power supply hardware with the more capable Kenwood D710G transceiver and its internal data controller, plus the custom-built MVPS. The new IORS equipment is common to both the US and Russian Operating Segments and their different power systems. This provides a redundant equipment set that can be moved from one ISS segment to another as necessary and without the need for reconfiguration. It also allows the possibility of simultaneous operations, such as a voice repeater in one segment and a digipeater in the other. As such, the IORS represents a vital upgrade to the ARISS system.

ARISS Interoperable Radio System Multi-Voltage Power Supply Thermal and Noise

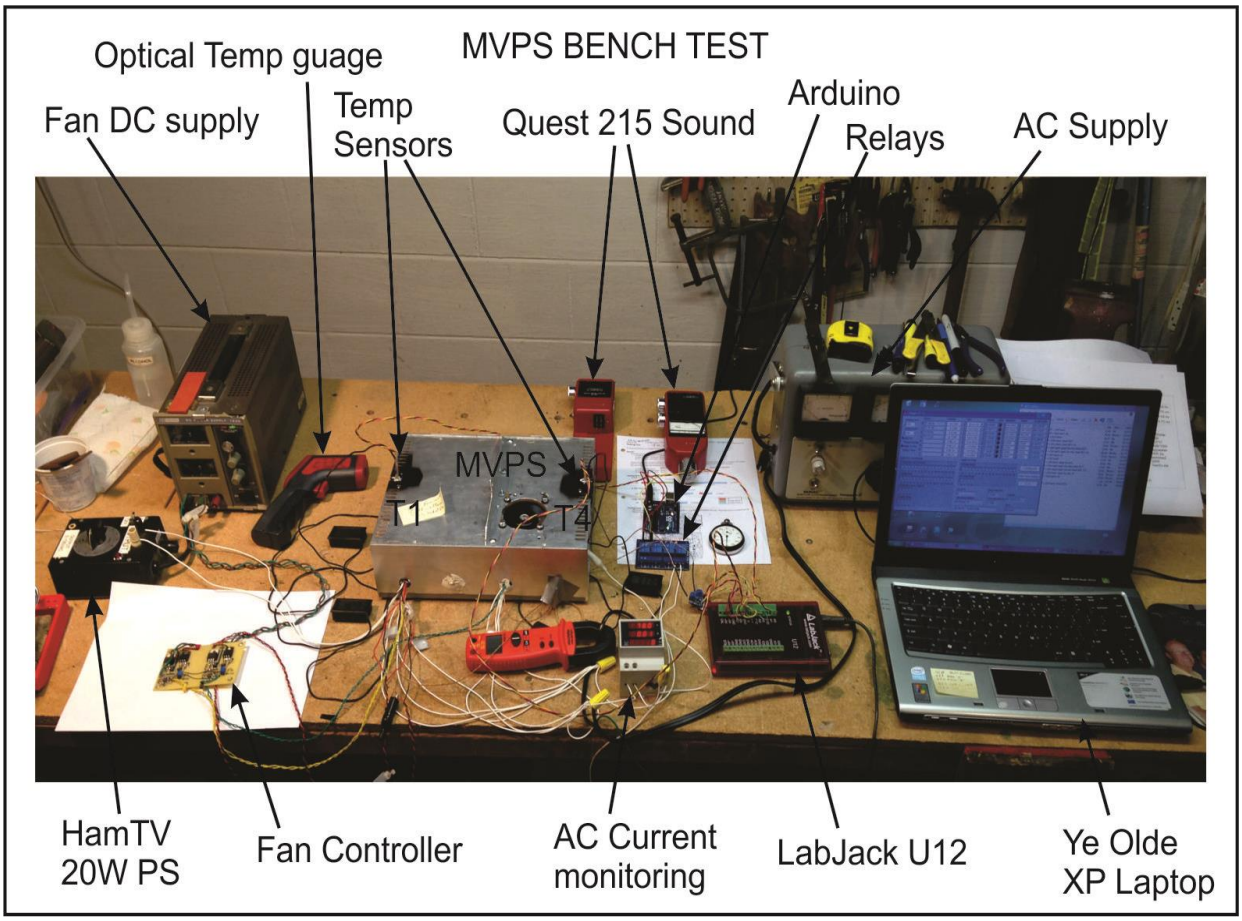
Ed Krome K9EK

Sounds easy… a box with a couple of DC-DC converters to power the new specially modified JVC Kenwood D710GA radios scheduled to be shipped to the ISS to replace the 10+ year old radios. But the spec has a few requirements. NASA is not at all concerned about how well something works; what they are concerned with is crew safety and lack of interference with anything else on ISS. And it has to be fool proof, requiring as little crew input as possible. The MVPS must be capable of being plugged in anywhere on ISS and work properly without modifications. This gets complicated as the Columbus (US) side runs of 120VDC and the Service module (Russian) runs on 28VDC.



When plugged in anywhere, the power supply has to power the D710GA radio, 13.8VDC@13A, the HamTV system, 28VDC@7A, SSTV, 6VDC@1.2A and 4 USB 2.3A ports. It also requires pass-through ports. NASA requirements include a wide variety of EMC, power quality, magnetic field, ESD, grounding, over voltage, over current, transient protection and disconnect functions, as well as touch temperature and acoustic (noise; both continuous and intermittent) requirements. And Russian requirements. The resulting device, designed (and brassboard prototype built) by Kerry Banke N6IZW, is shown at board level here. This device was extensively tested at JSC and accepted.

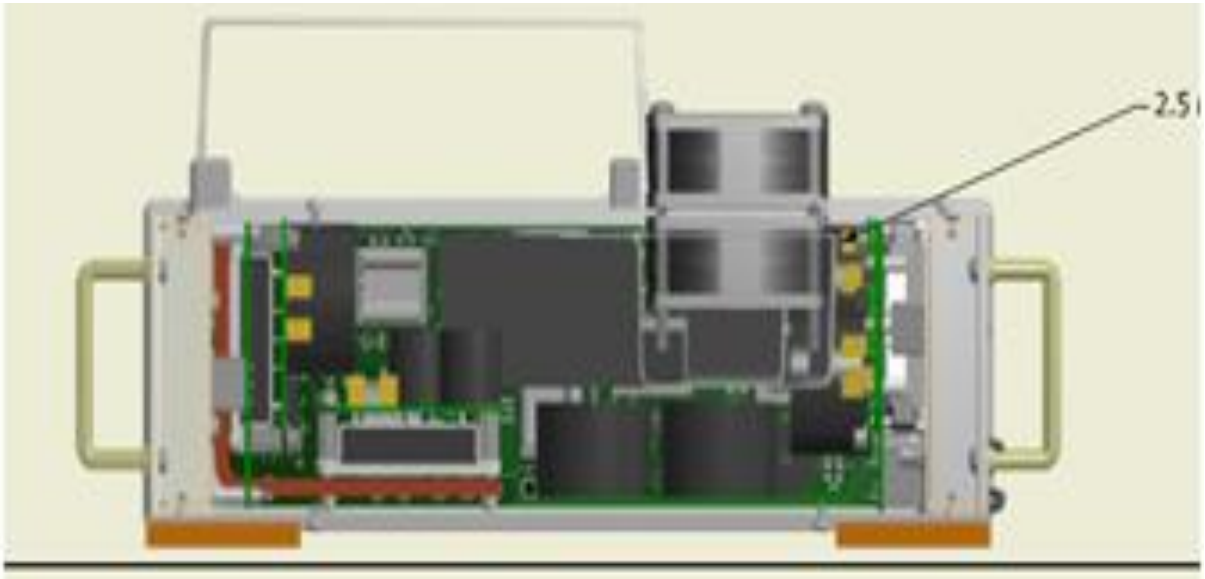
While a whole crew of folks has been involved with the project, Frank Bauer KA3HDO is the PI/PD, Lou McFadin W5DID is the Engineering Manager and the mechanical design for all this stuff was by Bob Davis KF4KSS. An early question was how to fit all this in a fairly small box (280mm x 232mm x 88mm) and keep it all cool. At full load, there is approximately 80 watts of heat that must be dissipated. Zero gravity has a lot of quirks. Heat is transferred by conduction, radiation and convection, the last of which is very common on Earth. But in space, with no gravity, hot air doesn't rise. There is no natural convection. Hot air just sits there. So cooling is through forced convection by fans. The case has two side heatsinks. The fan system needed to be simple, foolproof and redundant, so we ended up with 2 identical thermostatically controlled fans in series, with the requirement that either fan must be able to carry the full heat load. Air flow enters from the top and is directed by baffles over the internal components and through the heatsink fins, exiting on the sides. With five DC-DC converters, there isn't enough physical space to put each converter directly on the heatsink. After quite a bit of head scratching, the solution was to put two of the 13.8VDC converters on a heavy copper angle bracket, attached to one heatsink. This sounds like a big load, but the D710GA does not run at 100% duty cycle, so continuous full load dissipation is not required. Mathematical analysis indicated that the 3/16" thick x 4" wide strip of copper could satisfactorily transfer the heat from both converters to the finned heatsink. But we needed to be sure.



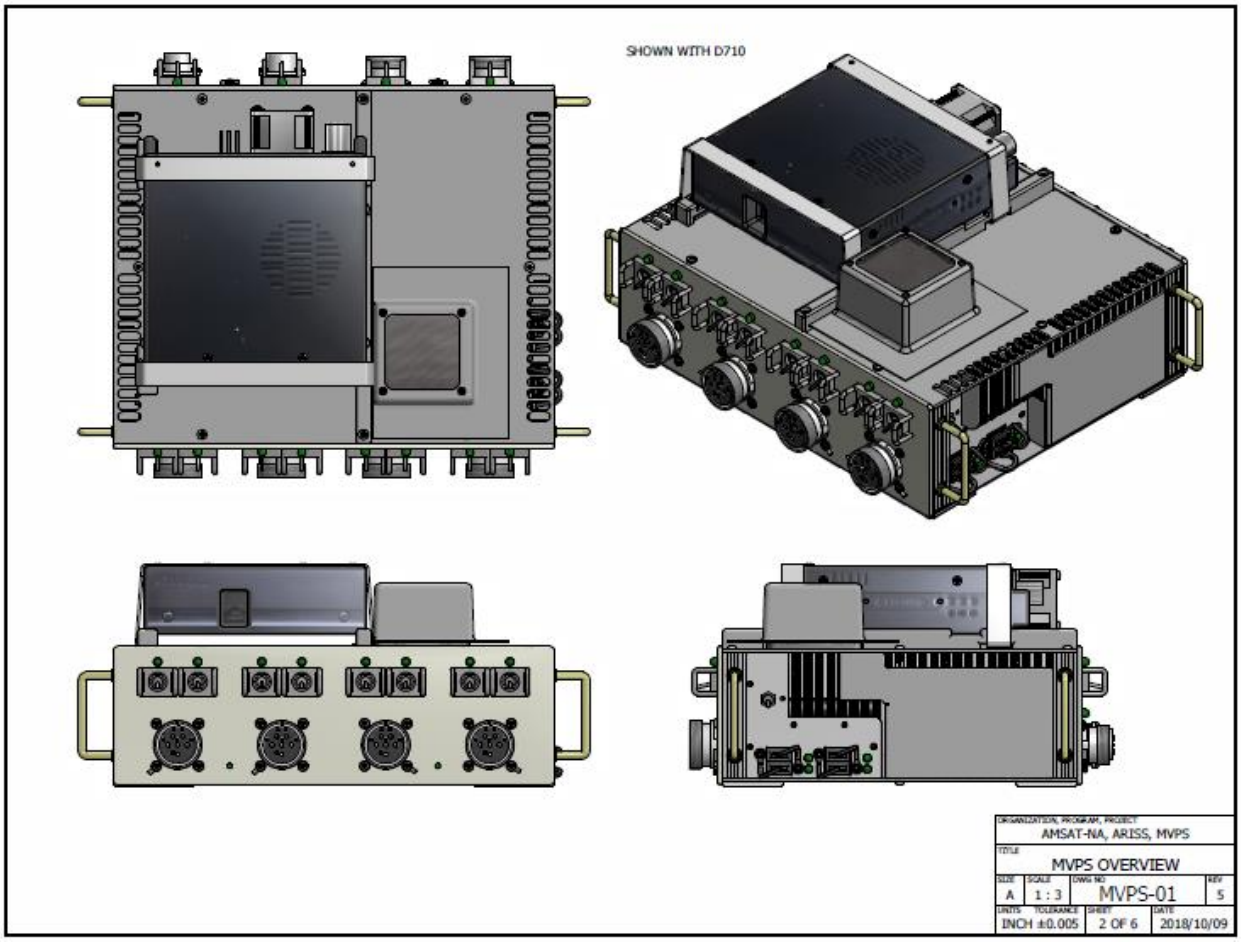
To verify a concept, you need to test it. So, for initial testing, I built up a test device with an actual case machined to final dimensions, then fitted it with heat sources sized to duplicate the actual DC-DC converters. These sources were lug mount resistors on aluminum plates. Heat was generated by AC voltage applied to each resistor. The case was instrumented with both thermocouples and solid state temperature sensors. Readings were checked with an optical temperature sensor. Sensors were calibrated and correlated. Tests were carried out under continuous load conditions (and overload conditions) in order to determine just how much safety margin was available. Fans were run at various speeds. The net resultant was resized (smaller) fans.

But the real world can be different. Kenwood has defined the D710GA duty cycle requirements for three scenarios; 25W voice, 10W digipeater and 5W repeater. Other outputs are defined as either 100% duty or off. A level 2 test was designed to simulate defined worst case. The 28V, 6V and USB were heated as 100% duty cycle. The D710GA load cycle was simulated by an automated load system from an Arduino microcontroller turning the heat load on and off. Separate tests were run at each of the 3 load profiles. The fans were automatically controlled; separate controllers sensed different heatsink temperatures, with fan speeds responding to the highest sensed temperature. Temperatures were recorded with an automated Labjack data acquisition system on an XP laptop. I could set it up, start it and sit back. Test results were quite good; temperatures did not exceed 37^{o}C. Our goal was less than 41^{o}C; NASA requirements are 45^{o}C. The cooling system was deemed adequate.

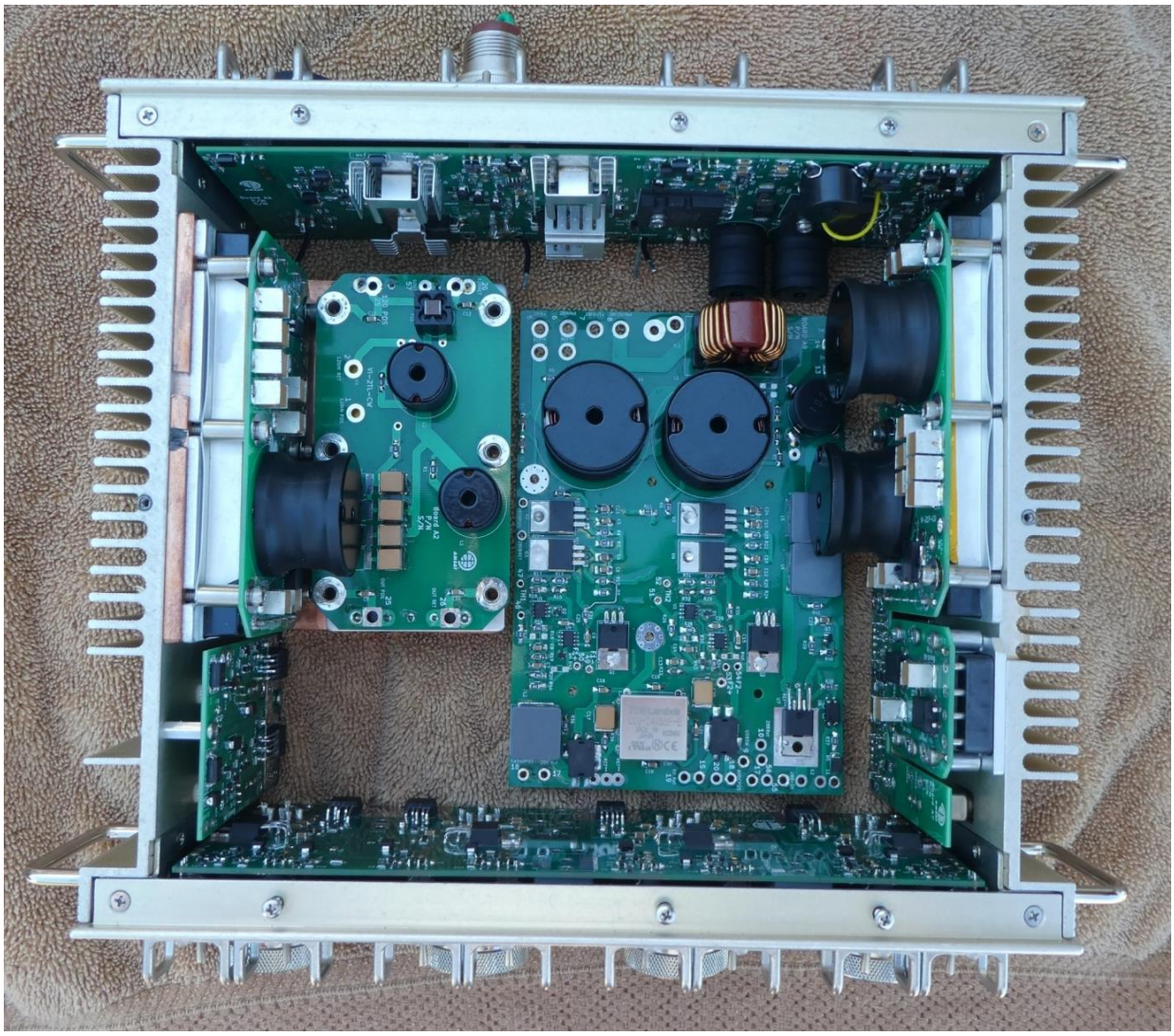
Then another requirement raised its head. Noise. NASA has specific intermittent and continuous acoustic level requirements, including levels within different frequency octaves and durations. I had borrowed a sound level meter capable of doing octave measurements. And the results were not good. The fans were just too noisy. This started a sequence of trials of different sound damping methods, including both unbaffled and baffled air boxes and boxes lined with special acoustic absorption foam. Nothing worked particularly well, dropping 1-2 dBA when we needed to drop 10+ dBA. The ultimate solution was to change fans. The original 40mm fans were replaced with slower turning 60mm fans. They are almost silent at normal operating.



Banke was continuing his electrical testing and found an unexpected glitch. Since the MVPS must be widely applicable with no crew-initiated changes, it has “steering” diodes; electronic one-way valves. Any semiconductor has a voltage drop in conduction; at load, two diodes on the Connector IN board got unacceptably hot. Kerry’s solution was to make an air duct to funnel part of the cooling air over the offending diodes. This worked fine, but the duct took up so much space, there was no longer room for both fans inside the box. The solution was to keep one fan inside the box and the second outside the box. This required design of an external “tower” to contain the fan, as well as mount the cleanable fan filter. But, of course, this physical change to the outside of the envelope required submission and review by NASA.



The next step is to build 10 of the actual units. Four will fly (one US, one Russian with backups), three will be for training (US and Russian), one will be flight-identical, one for Engineering test and one for software development. We also have other rounds of testing, both by us for thermal and noise, and of the flight-identical unit for NASA requirements at JSC. The model on the right shows the MVPS output side with the D710GA mounted (less its remote face/control unit) and the fan/filter input air tower. The USB ports are on the right side heatsink. The input connectors are on the face opposite the outputs. The cooling air outlets are along the top edge of the case and the upper edges of the heatsinks on both sides. Note that the heatsink fins are shrouded; this is part of the cooling air directing system.



This photo shows the interior of the flight-identical unit less interconnecting wiring. The big shielded inductors are parts of the power quality and filtering systems. The DC-DC converters are under those conditioning boards. The edge of the copper heat transfer angle bracket is visible along the far left heatsink.

This has been a really interesting and worthwhile project with far reaching impact on the next generation of students around the world. We really need more folks in science, technology, engineering and mathematics.

Experimental satellite antenna by G0UYT
Name : Double open cube antenna or Bird Cage (You decide!)

Brief : To design an antenna that works both on 2 meters and 70 cms.
Single feed, no duplexer, easy to construct, gain over a dipole.

Inspiration and antennas of note: EZ- parasitic Lindenblad antenna for 70cms,
Eggbeater version 2
2m & 70cms open sleeve vertical dipole.

So the theory

A simple vertical dipole fed and designed for 2 meters. Constructed on a 22mm Water pipe (white PVC)
Add to this a simple 70cms radiator mounted 180 degrees (opposite side of pipe) as per an open sleeve duel band dipole.

Add to this two - 2 meter quad loops similar as in the eggbeater antenna Mk2,
add to this 70 cms version of loops but within the inner area of the 2 meter loops at 45 degrees offset from the 2 meter loops. (see diagram)

Note these loops are simply parasitic and not driven.

The idea is that the loops are energised by the dipole on transmit, providing
Both vertical and horizontal polarisation (not circular)

On receive the loops act as additional gain for the dipoles energising
the dipoles once again.

To test this theory I simply built the vertical open sleeve dipole for the 2M & 70cms band and located the antenna around 3 meters from the ground.

Over a week of testing I was able to listen with difficulty to Ao91, Ao92 on passes between
20 – 40 degrees elevation with the usual fading etc.

Ao85 was heard on occasions and So50 was not heard at all.

Once I assembled the loops, I was able to copy So50 on passes above 50 degrees and the
other three with much better signal to noise and higher elevations e.g 30-75 degrees.

So I decided to mount the antenna at around 6 meters from the
ground attached to a pole from the house to try and work SSB transponders such as F029 and A07.

Much to my surprise I was able to work contacts on F029 with only 15 watts from my FT100D.

From my locater square IO92AK I worked stations including HA6NM,
IK8XLD, F4DXV, ON4CJQ PE1NIL EA2AZW, UT9NA.
All something I couldn't do with just a simple dipole set up. So this antenna certainly showed some gain over a dipole and appears to be omnidirectional, good with signals from as low as 10 -90 degrees and uses a simple single feed.

All good so far!

With the FM satellites the reports were just as good working across the UK and European stations.

I have since built a true eggbeater style antenna for comparison and they compare very close.
I would say the egg-beater has the edge for lower elevations on receive but I plan to experiment with a similar ground plane to pull down lower elevation signals.

It appears to be good for high elevation passes with no noticeable nulls when satellite is overhead (unlike my fixed beams on a rotator).

The difficult bit was trimming and tuning the 2 meter dipole once the loops had been added for a good match SWR.

I added a quality trimmer -15-85pf to the feed point of the 2meter dipole and tweaked for best match.

2meters 1:4 , 70cms 1:1

So quite acceptable

This is in no way a perfect design but just something I dedicated a bit of time to taking inspiration from other antennas.

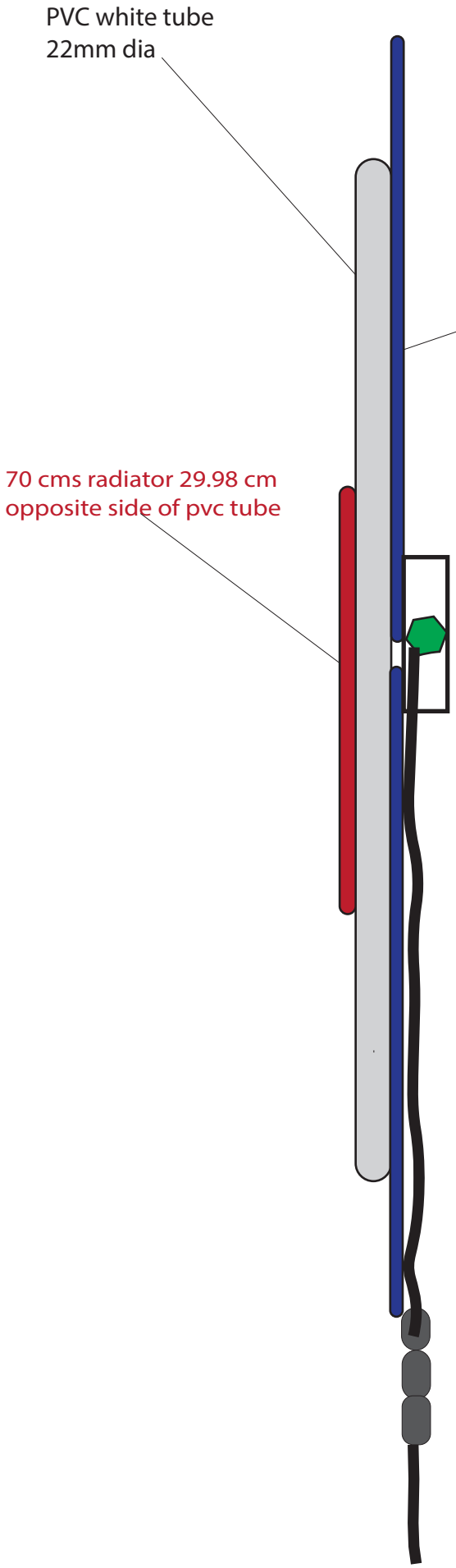
I always think that proof is in the pudding and this one works.

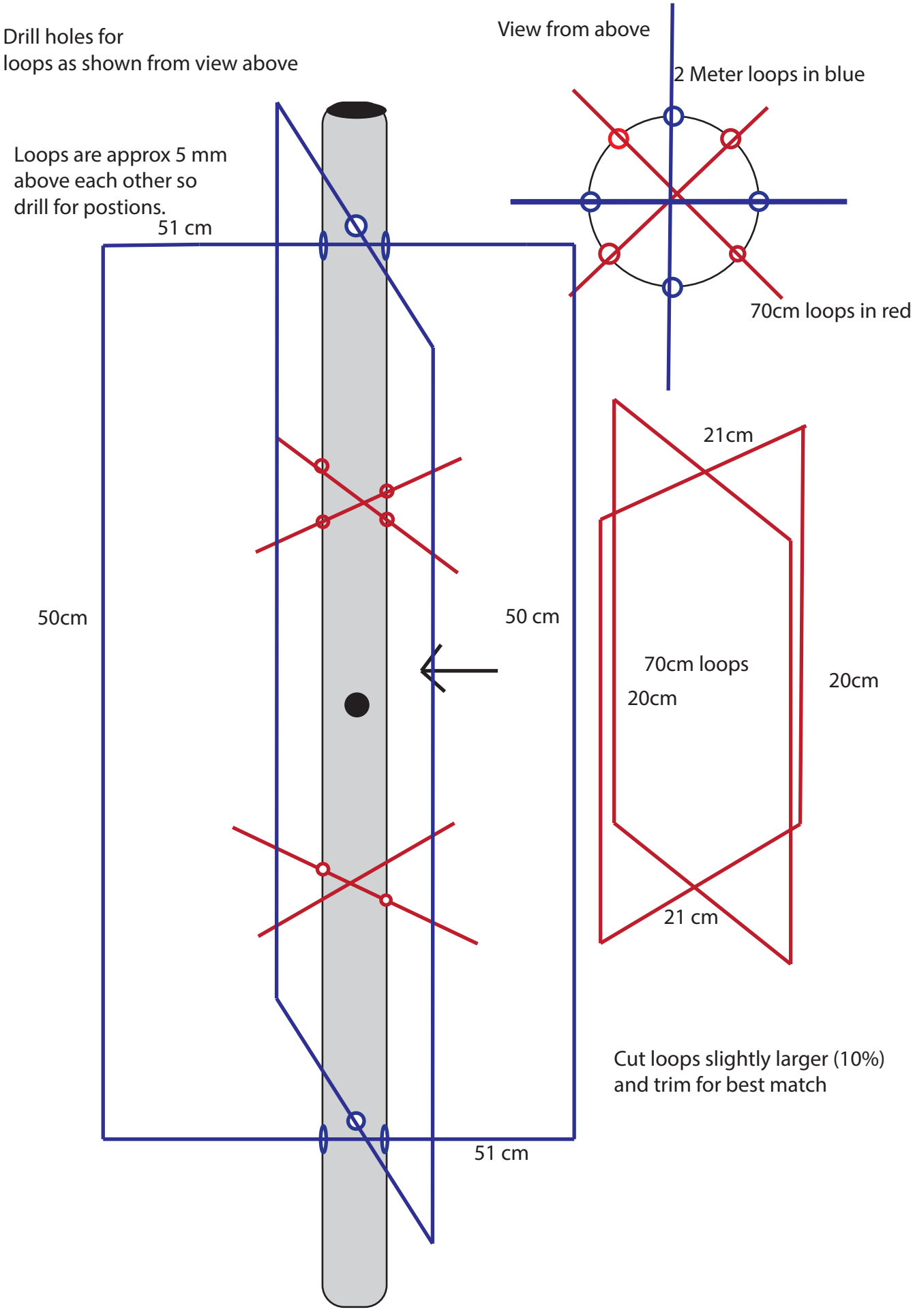
I am also sure that someone who has more knowledge of such antenna could add changes and experiment even further.

I would love feedback on any such experiments.

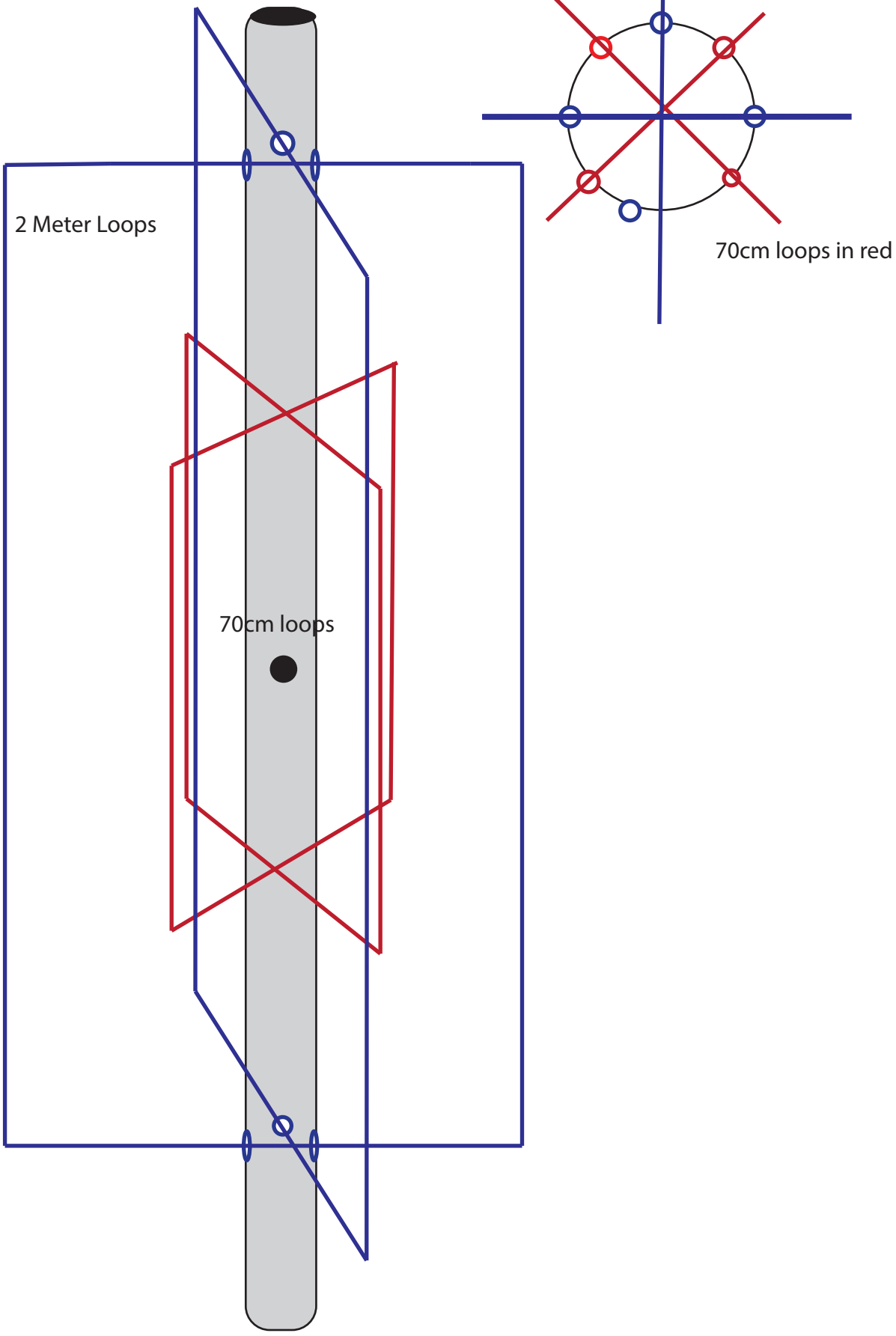
John Hemming
G0UYT

Dipole assembly

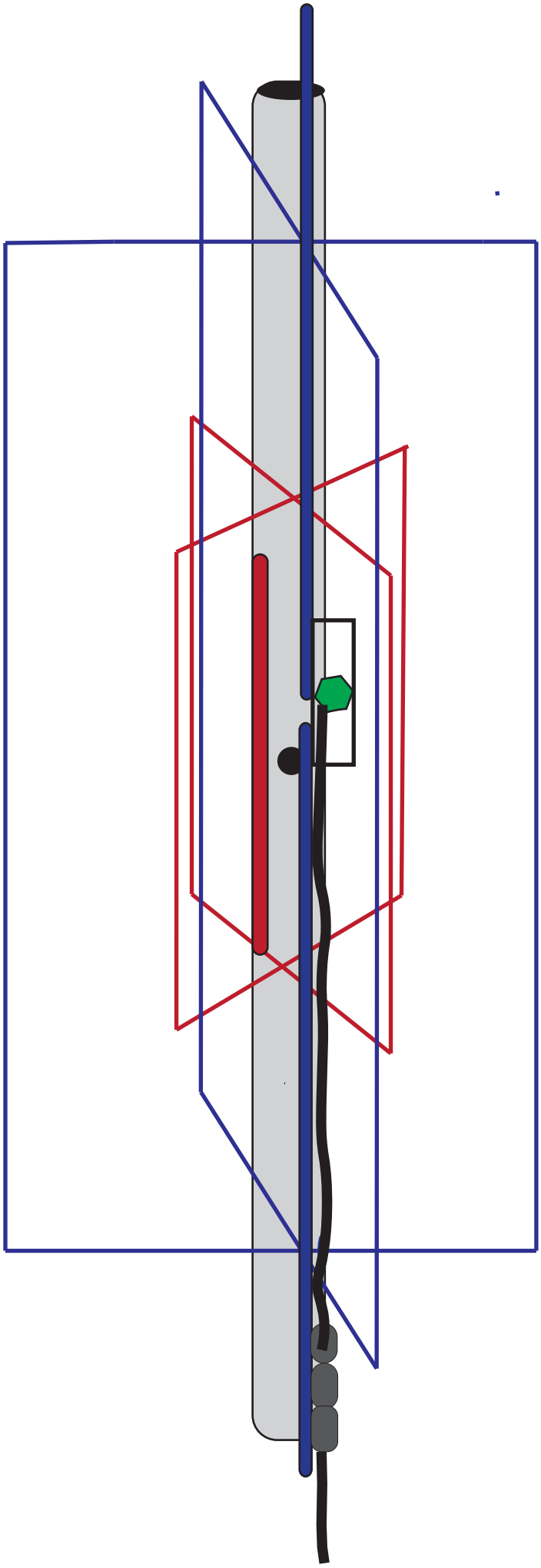

PVC white tube
22mm dia
basic open sleeve design for vertical dipole for 2M/70cm
2 meter dipole
each leg approx 49.3 cm (cut for best SWR so start over sized)
70 cms radiator 29.98 cm
opposite side of pvc tube
Make dipole legs from 1.8-2mm of copper or steel wire (pvc covered)
Feed dipole with a trimmer/capacitor 5-85Pf for best match once completely assembeld.
connections in a weather proof box for feeding Mini 8coax and housing trimmer.
5 Ferrite beads over coax once clear of dipole element

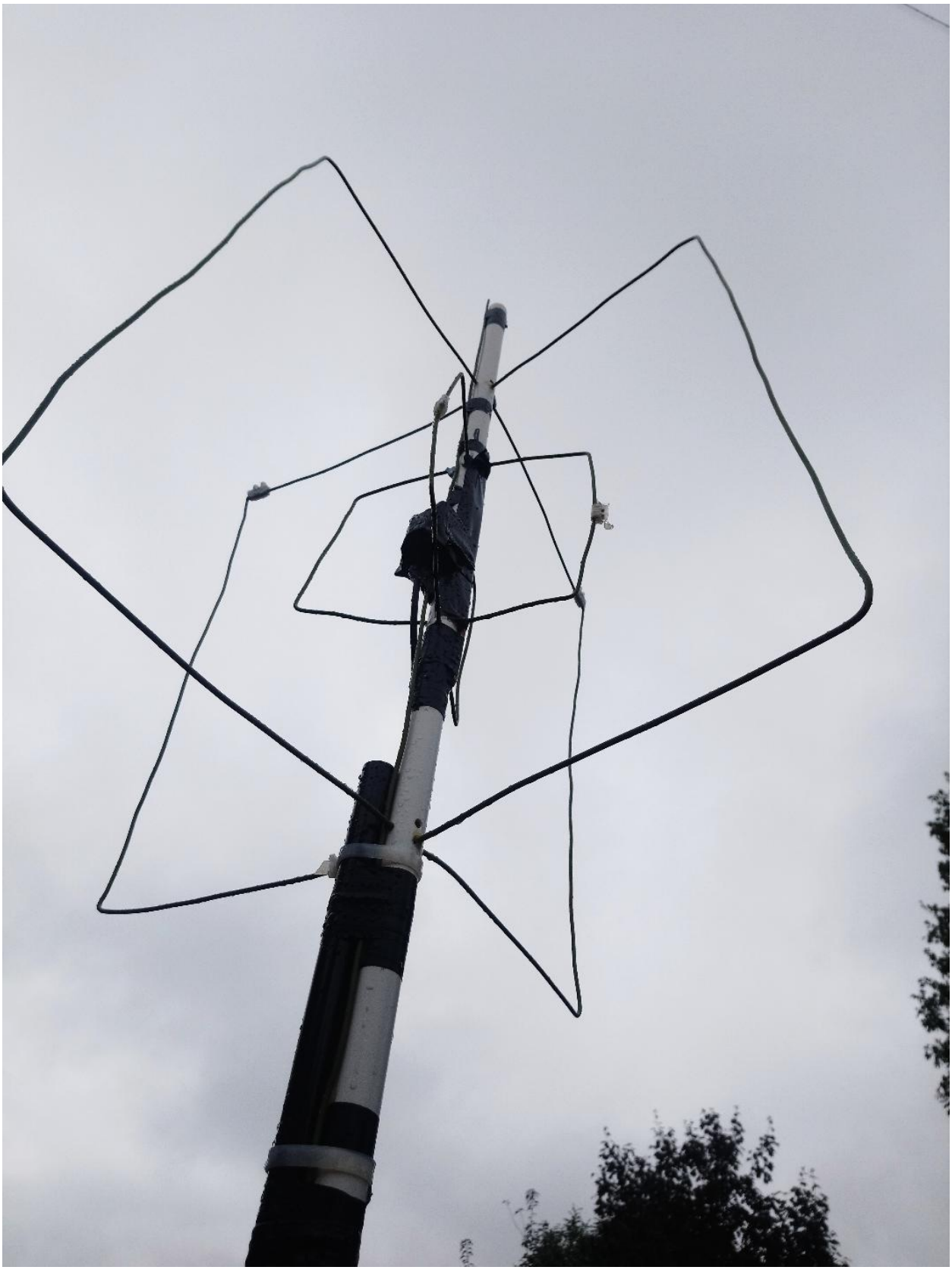

Drill holes for
loops as shown from view above
Loops are approx 5 mm
above each other so
drill for postions.
51 cm
50cm
50 cm
51 cm
View from above
2 Meter loops in blue
70cm loops in red
21cm
70cm loops
20cm
20cm
21 cm
Cut loops slightly larger (10%)
and trim for best match

Loop positions



Antenna assembled





DEPARTMENT OF SCIENCE AND TECHNOLOGY (DOST)
& UNIVERSITY OF THE PHILIPPINES (UP)

AMSAT-PHL

Micro and Nano-satellites with Amateur Satellite Ground Station Development Activities in the Republic of the Philippines

L. M. Almazan (WA6LOS/DU3ZX), A.C. Salces (DV1ZBJ), C. D. M. Ambatali (DV1QNE), Dr. J.S. Marciano, Jr., I.Z, Bautista (DV1PUI), Hanns Chua (4F1XIH)

[November 3, 2018]

Abstract

The Philippines, being a disaster-prone country, relies on datasets from satellites for a multitude of remote-sensing applications. In response, its Department of Science and Technology (DOST) supported the Development of the Philippine Scientific Earth Observation Microsatellite (PHL-MICROSAT) program with the aim to build, test and launch Philippines' earth observation satellites while developing more advance capacity through deep, intensive study, leading to the actual development of important satellite technologies. One of the paths that a team of students, instructors and engineers at the University of the Philippines (UP) Electrical and Electronics Engineering Institute (EEEI) have taken is the development of both micro and nanosatellites and the formation of AMSAT-PHL. This paper describes some of the accomplishments of the team in the development of its own amateur satellite ground stations and its current micro and nano satellite development programs.

Background

Despite its rich natural resources and genuine allure, the Philippines' geographic location in the Pacific has made it one of the most disaster-prone countries in the world. Filipino scientists spend great amount of expenditures procuring images from commercial satellite image providers for more scientifically based urban planning, flood control, resource mapping and weather forecasting. These images are not only expensive, but are also limited in terms of quality and quantity. Moreover, the overhead between date of order and delivery makes it unusable for time-critical applications such as disaster response. In response, the Department of Science and Technology (DOST) supported the Development of Philippine Scientific Earth Observation Microsatellite (PHL-MICROSAT) program with the aim to build, test and launch the Philippines' micro and nano observation satellites. It addresses not only the need for relevant and timely satellite data for remote sensing applications, but also the need to develop capacity through deep, intensive study leading to the actual development of important satellite technologies. The program is a joint effort between DOST, the University of the Philippines, Hokkaido University and Tohoku University in Japan.

Microsatellite and Nanosatellite Development at UP EEEI

The satellite development program of the Philippines has produced three low earth orbit (LEO) satellites: (1) *Diwata-1* (2) *Diwata-2* and (3) *Maya-1*. Both Diwata-1 and Maya-1 are now in low earth orbits and Diwata-2 is set to launch on October 29 of 2018.

Diwata-1

Diwata-1 also known as PHL-Microsat-1, was the first Philippine microsatellite deployed into the International Space Station (ISS) and was launched into orbit in April 27, 2016. It is the first Philippine microsatellite and the first satellite built and designed by a group of Filipinos engineers and PhD students. Moreover, It was the first satellite made possible through the Philippine Scientific Earth Observation Microsatellite (PHL-Microsat) Program, a three-year program funded by the Philippines Department of Science and Technology (DOST). Diwata-1 was also a part of the Hokkaido University and Tohoku University of Japan initiated project to send 50 microsatellites into space by 2050. The project objective was to photograph aftermaths of natural disasters, partnering with governments, universities and other organizations based in Bangladesh, Indonesia, Malaysia, Myanmar, Mongolia, Philippines, Thailand, and Vietnam.

In 2013, following the aftermath of Typhoon Haiyan (locally known as Typhoon Yolanda), the government paid close to $1.2 million for satellite imageries of the areas affected by the typhoon dubbed as the "Yolanda Corridor". This led to the creation of the PHL-Microsat program. The program was collaboration between the University of the Philippines, the DOST-Advanced Science and Technology Institute (DOST-ASTI), and Japan's Tohoku University and Hokkaido University.

A team of nine Filipino engineers from the DOST- ASTI and the University of the Philippines, were responsible for the production of Diwata-1 shown in Figure 1 and collaborated with scientists and engineers from the two Japanese universities. The assembly and testing of Diwata-1 was completed in December 2015.

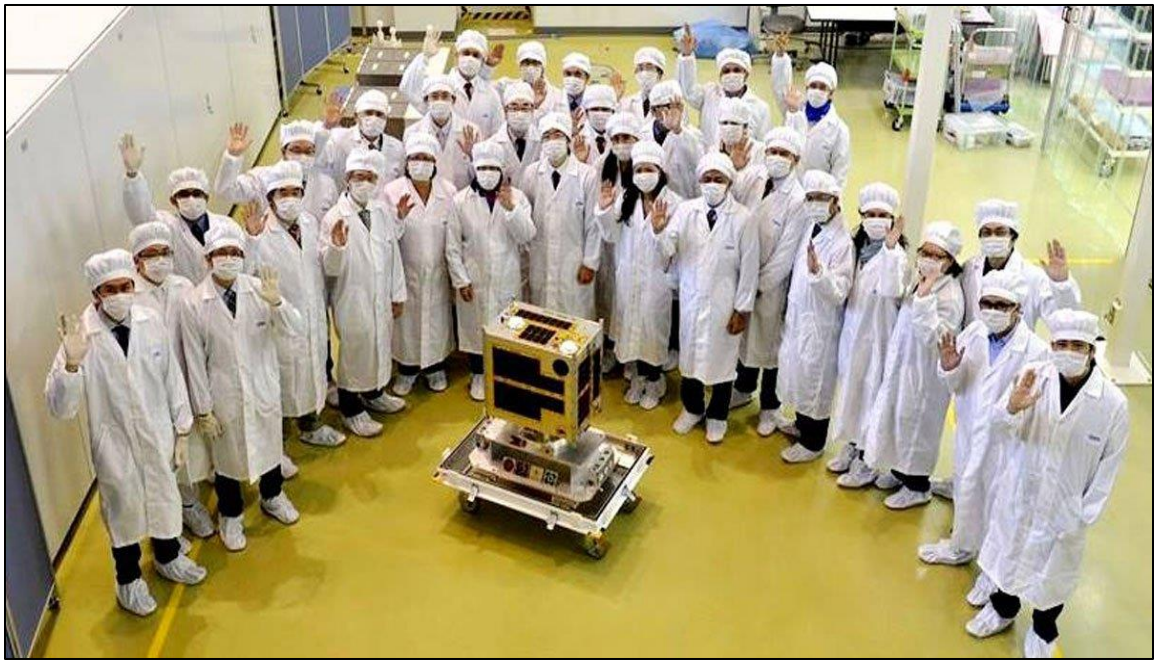


Figure 1. Diwata-1 and the Japanese and Filipino Team of Developers

Diwata-1 has three scientific instruments: the High Precision Telescope (HPT); Space-borne Multispectral Imager (SMI) with Liquid Crystal Tunable Filter (LCTF); and the Wide Field Camera (WFC). Diwata-1 also has one engineering control instrument, the Middle Field Camera (MFC). Diwata-1 was launched into the International Space Station onboard the Orbital ATK's Cygnus spacecraft on March 23, 2016. It was deployed from the ISS into her orbit on April 27 by the Japanese Experimental Module (JEM)—"Kibo" or Hope—around 400 km above Earth's surface. Figure 2, shows a photo of the Kibo Module.

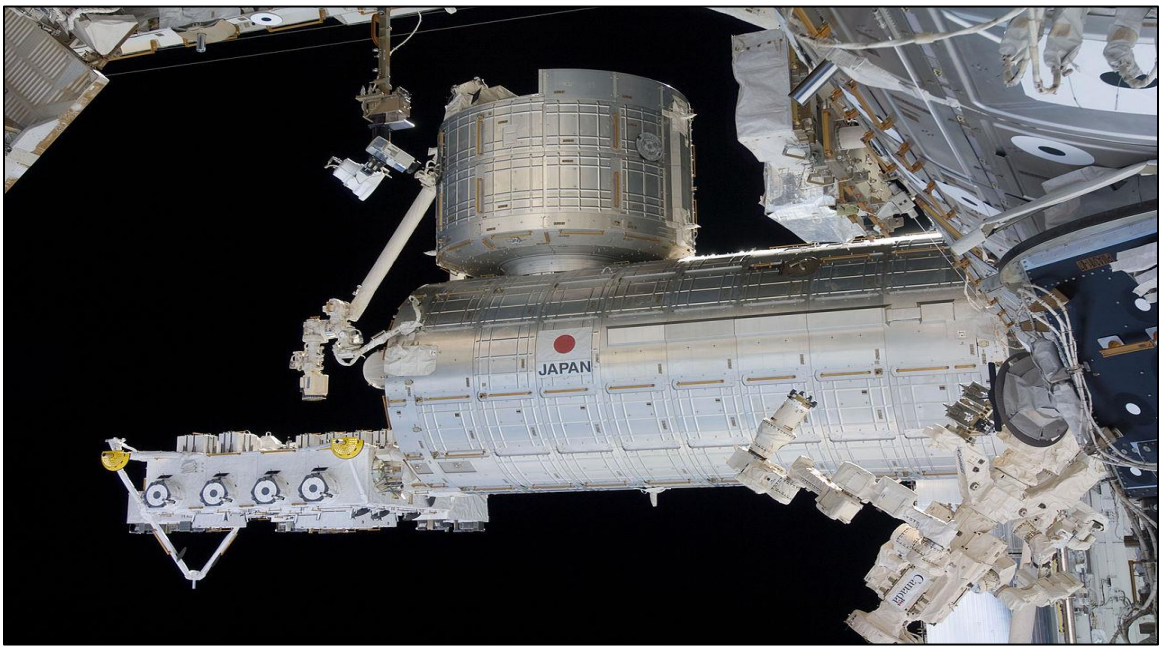


Figure 2. The Japanese KIBO Deployer aboard the International Space Station

The mission duration of the satellite was expected to take place for around 20 months, 2 months longer than earlier reported. It has since surpassed that. The engineering team behind Diwata-1 at the Tohoku University was able to receive the satellite's first communication hours later after its deployment from the ISS, at 7:45 p.m. PST

A ground station based in the Philippines, the Philippine Earth Data Resources Observation (PEDRO) Center, has primary control over the satellite with a command line on the UHF band. PEDRO receives telemetry data sent by Diwata-1 via UHF band and receives images via X-band. Diwata-1 was operational a week after its deployment into orbit.

The satellite's first images were released in public by the Tohoku University on June 2, 2016, via a Japanese press release. The satellite shot images of Isabela province, northeast of the island of Luzon, is shown in Figure 3. It has also captured images of the coastlines of Palawan in the western Philippines, showing signs of siltation on certain parts of the coastline as shown in Figure 4.

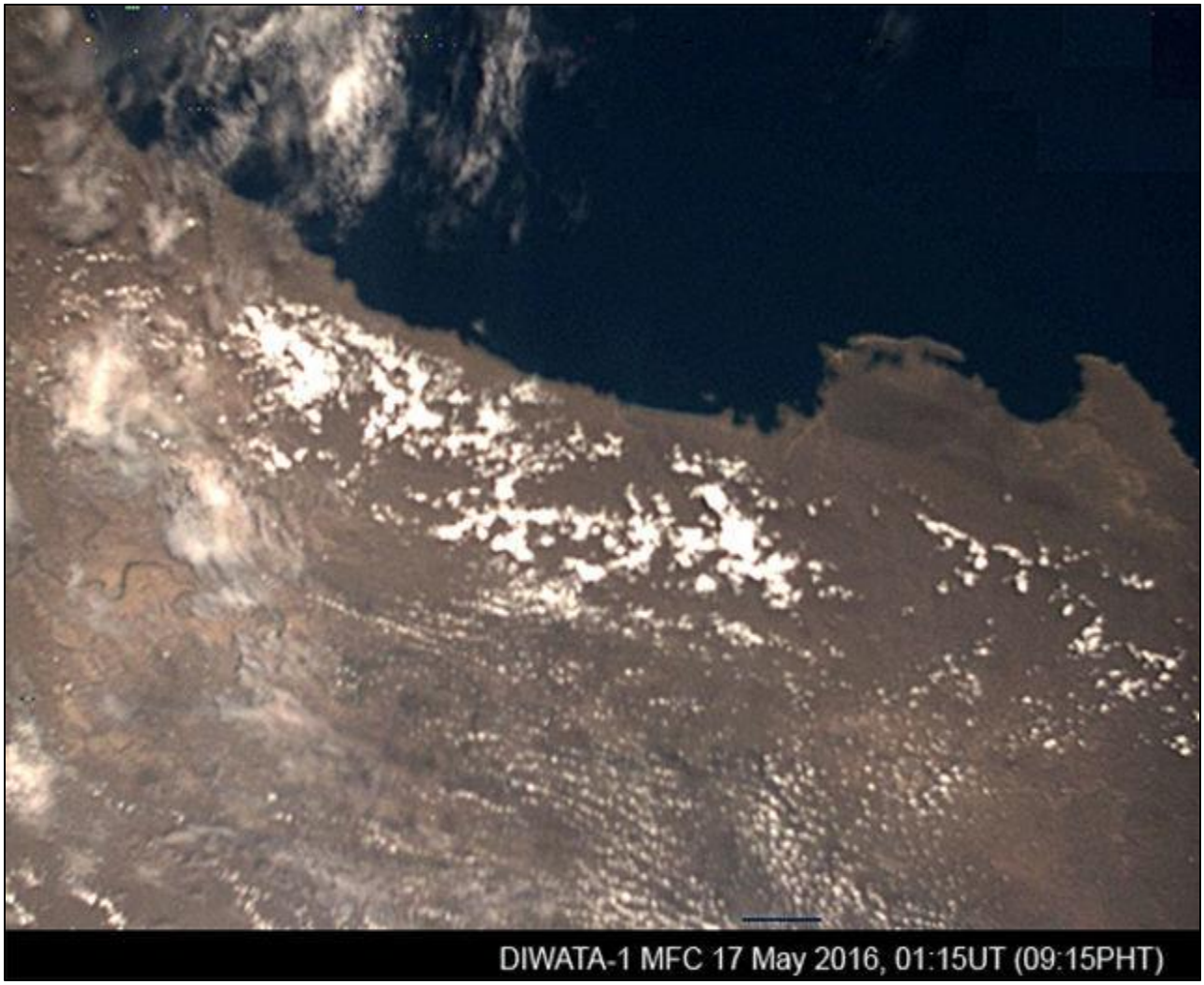


Figure 3. Image of the coastline of the province of Isabela

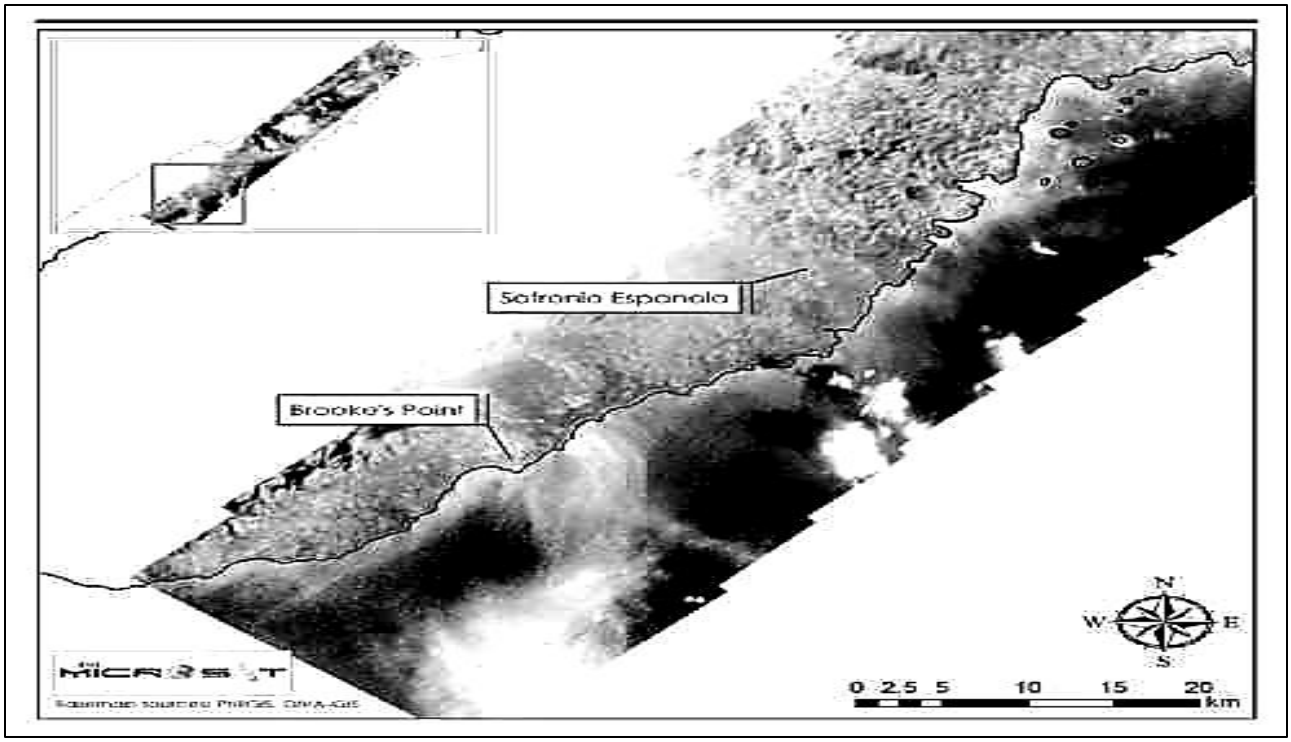


Figure 4. Photo of the effects of siltation in the province of Palawan

Diwata-2

Diwata-2 micro-satellite was designed and developed by Filipino scientists and engineers under the PHL-Microsat Program. It will host an amateur radio payload which will enable people in the Philippines to relay messages through ham radio to any part of the country. This function is meant for disaster relief and emergency operations.

The 50 kg satellite measures 50 cm × 50 cm × 50 cm. It features two deployable systems - solar array panels and amateur radio antennas. Diwata-2 will carry optical payloads that will support the following objectives:

- *Determining the extent of damages from disasters*
- *Monitoring natural and cultural heritage site*
- *Monitoring changes in vegetation*
- *Observing cloud patterns and weather disturbances*

Diwata-2 carries the following payloads to support its mission objectives:

- *High Precision Telescope (SMI)*
- *Spaceborne Multispectral Imager (SMI) with Liquid Crystal Tunable Filter (LCTF)*
- *Wide Field Camera (WFC)*

- *Middle Field Camera (MFC)*
- *Enhanced Resolution Camera (ERC)*
- *Amateur Radio Unit (ARU)*

The Space-borne Multispectral Imager (SMI) with liquid crystal tunable filter (LCTF) is used for environmental monitoring, and a high precision telescope (HPT) for rapid post-disaster assessment. Compared to Diwata-1 which hosted wide and middle field cameras, Diwata-2 will host enhanced resolution cameras (ERC) and a wider field-of-view or coverage of her other cameras, the multispectral imaging camera, the high-precision telescope, wide field camera and middle field camera. Moreover, Diwata-2 has a deployable solar array panels aimed at increasing her solar power charging capability as shown in Figure 5.

It will have the same mission as its predecessor, Diwata-1. However unlike Diwata-1, it will have a sun-synchronous orbit and will be directly deployed from the rocket that it will be hosted on and not from the International Space Station

Figure 5. Artist rendition of the Diwata-2 and its deployed Solar Panel

One of the Diwata-2's mission is to collect data from floating buoy sensors deployed offshore, a safe and better alternative than sending people to manually collect the data especially when the weather is not conducive for such operation. Several buoy sensors are deployed that will automatically collect the data from nearby sensors, and the buoy sensor collecting the data will upload it to Diwata-2. Sensor

data can then be downloaded when Diwata-2 passes over one of the ground receiving stations, and distributes it to the different stakeholders and end users . This Store-and-Forward mechanism is not limited to just specific sensors. Modification of existing and other legacy sensors such as flood monitoring sensors can be upgraded on the field so they can have the capability to upload data onto Diwata-2.

Diwata-2 also carries an attitude or orientation control that will help in pointing the satellite's cameras into a specific target on Earth. Figure 6, illustrates the different component placements on the satellite. In addition to the optical payloads, Diwata-2 carries an amateur radio unit (ARU). This payload is intended to promote awareness and interest in amateur radios and amateur satellite technology in the country. It is also intended to provide an alternative means of communication at times of disasters and emergencies.

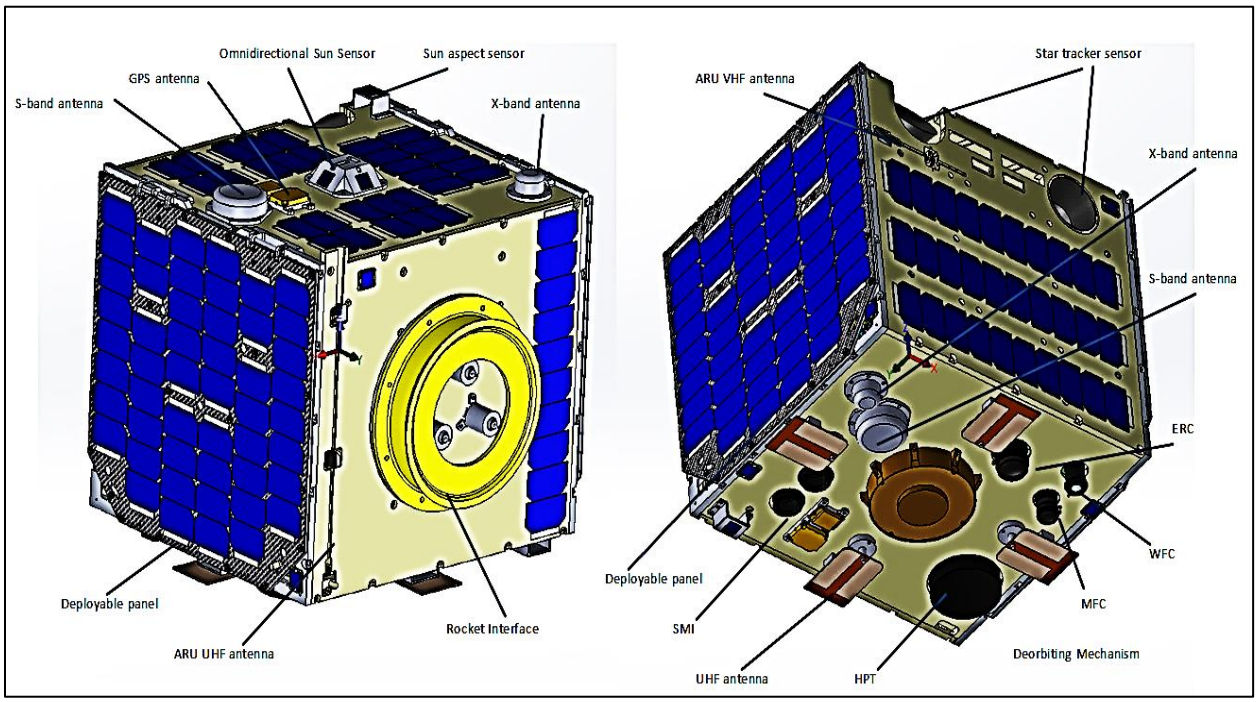


Figure 6. Components and placements on the Diwata-2 satellite

The International Amateur Radio Union has coordinated these frequencies for Diwata-2 as shown in Table 1.

Table 1.

Frequency	Communication Link
145.900 MHz	Downlink
437.500 MHz	Uplink

The amateur radio unit is intended to promote awareness and interest in amateur radio, satellite technology and AMSAT in the country. It is also intended to provide an alternative means of communication at times of disasters and emergencies.

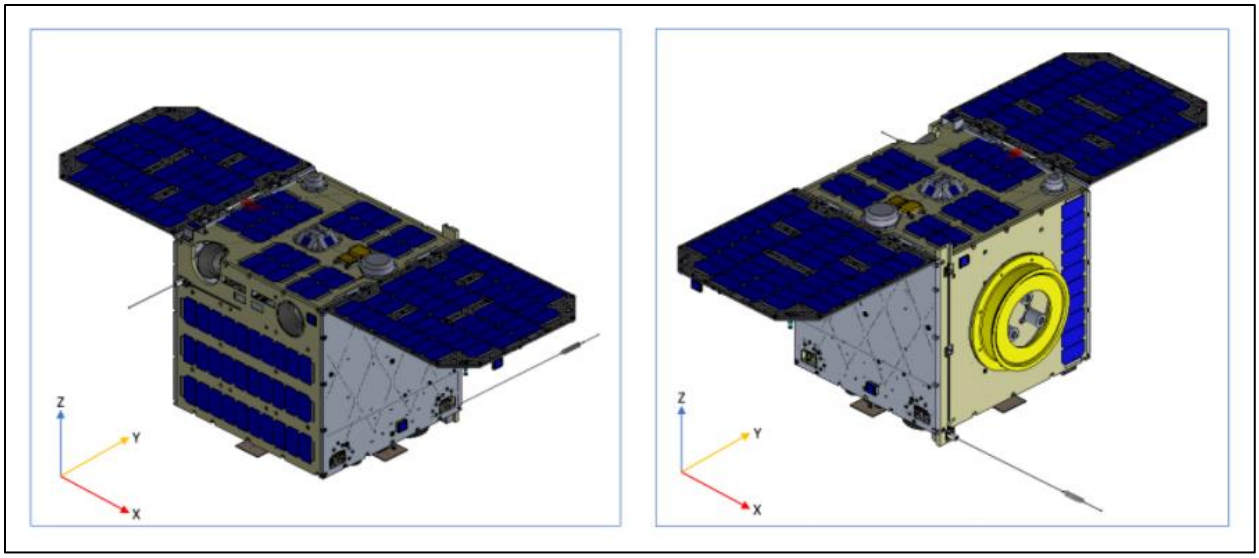


Figure 7. Diwata-2 Perspective Views of the Amateur Antennas Deployed

The placement of the amateur radio antennas was carefully considered in the structure due to its size and the need for an omnidirectional pattern as shown in Figure 7. There are a total of two amateur radio antennas, one for VHF and one for UHF band. Figure 8, shows the placement on the antennas in the satellite panels.

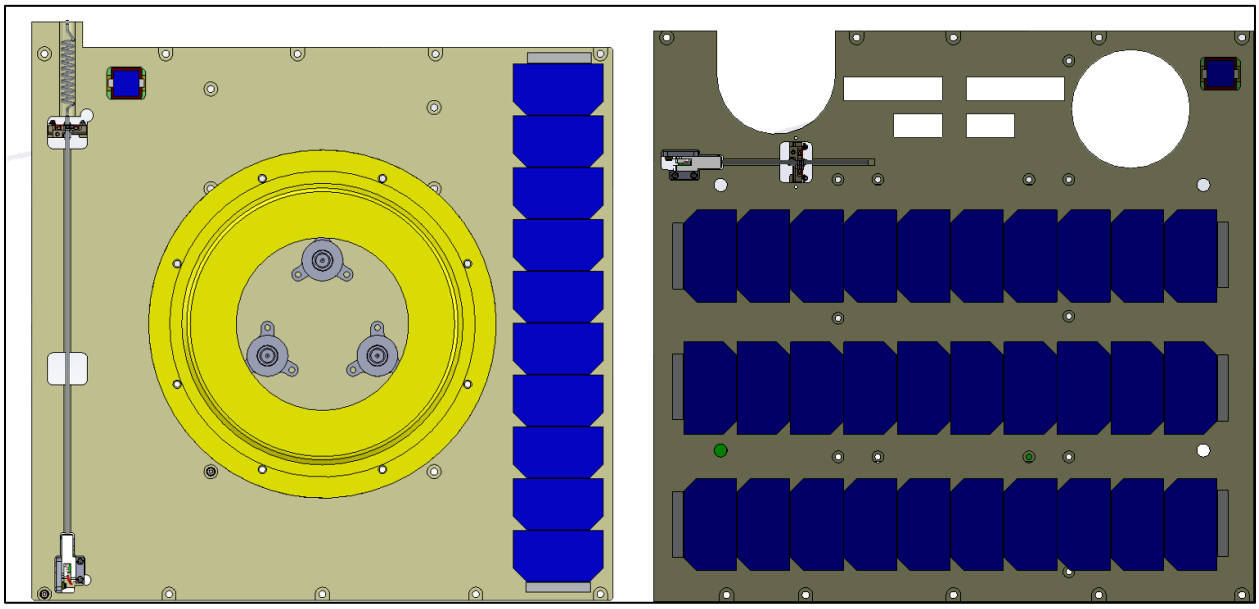


Figure 8. VHF/UHF Antenna Placements

The VHF antenna weighs 8.13g and measures 425mm. It has a matching network to reduce the antenna's physical length and be accommodated in the satellite panels. The UHF antenna weighs 1.6g and measures 135mm. Each antenna rod is made up of Al 6061 material with a diameter of 2.4 mm. It is coated with chromium anodic finish to regulate the temperature fluctuations of the rod in orbit, while

the termination is coated with a gold plated finish to facilitate soldering. Figure 9, shows the prototype of the VHF and UHF antennas.

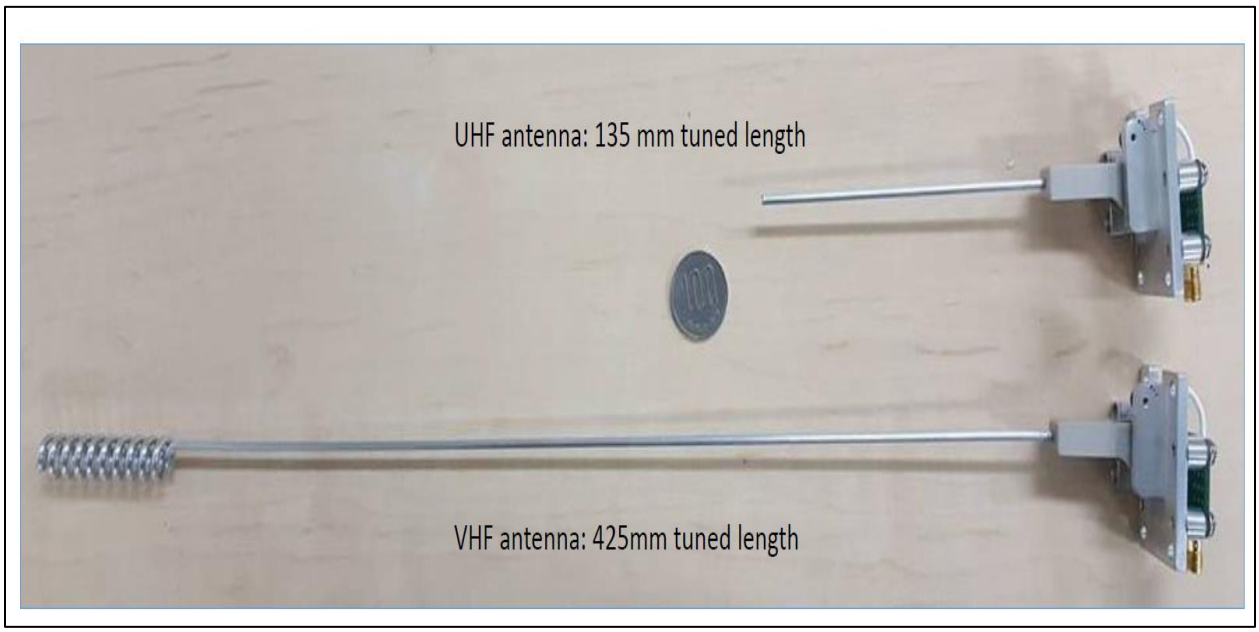


Figure 9. VHF/UHF Antenna prototype

Communication

This subsystem is responsible for sending and receiving data to and from the ground station. Diwata-2 carries a UHF-band receiver (URX), an S-band receiver (SRX), an S-band transmitter (STX) and an X-band transmitter (XTX). URX and SRX are used for receiving commands from the ground station. The SRX is used for transmitting housekeeping data and as a backup link for sending images to ground. The XRX is dedicated for sending images.

Power

This subsystem is responsible for providing power to different modules of Diwata-2. It consists of the power control unit, solar cells and battery. DIWATA-2 will contain deployable solar array panels (DSAP) to increase the power generation potential of the satellite. This improvement paves the way for the additional amateur radio communications unit, which is projected to consume an additional 3.96 W.

Command and Data Handling

DIWATA-2 contains two main On-Board Computers (OBCs). First, the Satellite Central Unit (SCU) will handle incoming satellite commands as well as outgoing satellite status telemetry. The other OBC is the Attitude Control Unit (ACU), which will calculate the required satellite control maneuver in order to satisfy the required satellite orientation to accomplish its mission. Aside from these two main OBCs, it is planned to add a peripheral ACU Support (ACUS) unit to delegate some of the time-critical calculations from the ACU. From this, it is hoped that a better overall Attitude Determination and Control performance will be achieved.

Attitude Determination and Control (ADCS)

To accomplish its remote-sensing missions, Diwata-2 is capable of capturing images of target locations with high accuracy. This is enabled through this subsystem. When Diwata-2 is tasked to capture an image, the ADCS points Diwata-2 to the target location. The ADCS for DIWATA-2 will include magnetic torquers (MTQ) for coarse attitude control and reaction wheels (RW) for fine attitude control. These controllers are used in conjunction with attitude sensors, which include sun aspect sensors (SAS), geomagnetic aspect sensor (GAS), and star trackers (STT). In addition, a fiber-optic gyroscope (FOG) is put in place to track the movement of the satellite and serve as a secondary source of attitude when the need arises. Additional high-accuracy sun aspect sensors and the aforementioned ACUS aims to improve the accuracy of attitude control maneuvers to error angle of below 1 degree.

A sampling of the Diwata-2 specification is shown on Table 2, below:

Table 2.

Specification	Value	Unit
Mean Orbital Altitude	600	[km]
Min DL Elevation Angle	10	[deg]
DL Center Frequency	145.9	[MHz]
DL Bandwidth	20	[KHz]
SC Tx Output Power (in W)	0.8	[W]
SC Tx Antenna Gain	4	[dBi]
SC Tx Power Delivered to Antenna (in dBm)	28.17	[dBm]
GS Rx Antenna Gain	13.4	[dBi]
GS Rx Sensitivity (for 12dB SINAD)	-121	[dBm]
GS Rx Desired Minimum SNR	10	dB

Telemetry Formats

The Diwata-2 amateur radio unit (ARU) provides telemetry data in two forms depending on its operational mode: CW (enabled in ARU voice repeater mode), and FM (enabled in ARU digipeater mode. As the two operational modes are scheduled according to the day of the week, the available telemetry differ in format and content correspondingly. This section explains the data format and specifications for the ARU telemetry.

Continuous-wave telemetry (CW)

The CW telemetry is available when the satellite is in voice repeater mode. The telemetry messages expected from the ARU will be sent every 1 minute, when the ARU is idle, i.e. there are no ongoing voice

operations. This said, the telemetry will not be available when the ARU is busy, and likewise, the telemetry transmission will be abruptly aborted when a voice repeating operation starts while in the midst of telemetry downlink. The data can be received in Morse code format of 120 WPM, at a frequency of 145.900 MHz. The pertinent data format is shown in Table 3, and further explained in the table that follows.

D1W2PH_DIWATA2_VR_$A_7A_6A_5A_4A_3A_2A_1A_0R_3R_2R_1R_0$_
$Y_3Y_2Y_1Y_0M_1M_0D_1D_0H_1H_0M_1M_0S_1S_0$_$B_2B_1B_0C_2C_1C_0T_2T_1T_0$_$V_4V_3V_2V_1V_0$

Table 3.

Data	Format	Characters	Description
D1W2PH	Alphanumeric	6	Callsign of Diwata-2 ARU
_	Alphanumeric	1	Space character
DIWATA2	Alphanumeric	7	Satellite name
_	Alphanumeric	1	Space character
VR	Alphanumeric	2	ARU operational mode (VR)
_	Alphanumeric	1	Space character
$A_7A_6A_5A_4A_3A_2A_1A_0$	Hex	8	Seconds in continuous operation, incrementing even when ARU switches operational mode. Can be used to track software or hardware resets Operating time is calculated as $T_{op} = A_7 \times 16^7 + A_6 \times 16^6 +$ $A_5 \times 16^5 + A_4 \times 16^4 + A_3 \times 16^3 +$ $A_2 \times 16^2 + A_1 \times 16 + A_0$
$R_3R_2R_1R_0$	Hex	4	Number of reboots/resets: the very first startup upon launch is counted as first reboot Number of reboots = $R_3 \times 16^3 +$ $R_2 \times 16^2 + R_1 \times 16 + R_0$
_	Alphanumeric	1	Space character
$Y_3Y_2Y_1Y_0M_1M_0D_1D_0$	Numeric	8	Date as registered in the ARU
$H_1H_0M_1M_0S_1S_0$	Numeric	6	Time as registered in the ARU
_	Alphanumeric	1	Space character

$B_2B_1B_0$	Hex	3	Battery supply voltage as detected by ARU $V_{batt} = (B_2 \times 16^2 + B_1 \times 16 + B_0) / 1023 * 15.0$
$C_2C_1C_0$	Hex	3	ARU supply current coming from battery supply $I_{batt} = (C_2 \times 16^2 + C_1 \times 16 + C_0) / 1023 * 10.0$
$T_2T_1T_0$	Hex	3	ARU temperature (ambient temperature inside enclosure) $I_{batt} = (T_2 \times 16^2 + T_1 \times 16 + T_0) / 1023 * 50.0$
_	Alphanumeric	1	Space character
$V_4V_3V_2V_1V_0$	Hex	5	Voice time: time (s) spent by ARU for the current day to forward voice messages $t_{voice} = V_4 \times 16^2 + V_3 \times 16^2 + V_2 \times 16^2 + V_1 \times 16 + V_0$

Each character in the CW string is a human-readable letter/number, and the hex-formatted numbers are encoded in the alphanumeric. For example, when the ARU has already operated continuously for 5678 seconds, this translates to 0x162E, hence the CW data can take the human-readable string **D1W2PH_DIWATA2_CW_0000162E_1F93**.

FM telemetry

Diwata-2 ARU in APRS digipeating mode provides FM telemetry, which is available at 145.9 MHz, 1200 bps AFSK. The data available in the FM telemetry are similar to that of CW telemetry, but also gives information on the EEPROM status. This EEPROM mainly stores messages to be forwarded at a scheduled time and date shown in Table 4.

D1W2PH_DIWATA2_DP_$A_7A_6A_5A_4A_3A_2A_1A_0R_3R_2R_1R_0$_ $Y_3Y_2Y_1Y_0N_1N_0D_1D_0H_1H_0U_1U_0S_1S_0$_ $B_2B_1B_0C_2C_1C_0T_2T_1T_0$_ $M_2M_1M_0E_2E_1E_0$

Table 4.

Data	Format	Characters	Description
D1W2PH	Alphanumeric	6	Callsign of Diwata-2 ARU
_	Alphanumeric	1	Space character
DIWATA2	Alphanumeric	7	Satellite name
_	Alphanumeric	1	Space character

DP	Alphanumeric	2	ARU operational mode (Digipeater)
_	Alphanumeric	1	Space character
$A_7A_6A_5A_4A_3A_2A_1A_0$	Hex	8	Seconds in continuous operation, incrementing even when ARU switches operational mode. Can be used to track software or hardware resets Operating time is calculated as $T_{op} = A_7 \times 16^7 + A_6 \times 16^6 +$ $A_5 \times 16^5 + A_4 \times 16^4 + A_3 \times 16^3 +$ $A_2 \times 16^2 + A_1 \times 16 + A_0$
$R_3R_2R_1R_0$	Hex	4	Number of reboots/resets: the very first startup upon launch is counted as first reboot Number of reboots = $R_3 \times 16^3 +$ $R_2 \times 16^2 + R_1 \times 16 + R_0$
_	Alphanumeric	1	Space character
$Y_3Y_2Y_1Y_0N_1N_0D_1D_0$	Numeric	8	Date as registered in the ARU
$H_1H_0U_1U_0S_1S_0$	Numeric	6	Time as registered in the ARU
_	Alphanumeric	1	Space character
$B_2B_1B_0$	Hex	3	Battery supply voltage as detected by ARU $V_{batt} = (B_2 \times 16^2 + B_1 \times 16 + B_0) / 1023 * 15.0$
$C_2C_1C_0$	Hex	3	ARU supply current coming from battery supply $I_{batt} = (C_2 \times 16^2 + C_1 \times 16 + C_0) / 1023 * 10.0$
$T_2T_1T_0$	Hex	3	ARU temperature (ambient temperature inside enclosure) $I_{batt} = (T_2 \times 16^2 + T_1 \times 16 + T_0) / 1023 * 50.0$
_	Alphanumeric	1	Space character
$M_2M_1M_0$	Hex	3	Number of stored messages in EEPROM $msg\_count = C_2 \times 16^2 + C_1 \times 16 + C_0$
$E_2E_1E_0$	Hex	3	% occupied storage in EEPROM $mem\_percent = (C_2 \times 16^2 + C_1 \times 16 + C_0) / 4095 * 100$

Maya-1

Maya-1 is a 1-U CubeSat nano-satellite developed under the Philippine Scientific Earth Observation Microsatellite program (jointly implemented by the University of the Philippines, the Department of Science and Technology and the Kyushu Institute of Technology-led multinational 2nd Joint Global Multination Birds Project (Birds-2). Maya-1 is the first of many nanosatellite that will be developed in the Philippines in the near future.

The satellite was developed mainly through the second Joint Global Multination Birds Project (Birds-2) initiated by the Kyushu Institute of Technology (Kyutech) in Japan. The project is managed by a team composed of 11 graduate students from Bhutan, Japan, Malaysia, and the Philippines. The two other satellites developed under Birds-2 are: BHUTAN-1 of Bhutan and UiTMSAT-1 of Malaysia. The first iteration of the project (Birds-1) was a joint effort by Bangladesh, Ghana, Japan, Mongolia, and Nigeria.

The Birds-2 project started in November 2016. Maya-1 was designed by PHL-Microsat scholars and Kyutech graduate students Joven Javier and Adrian Salces. Javier is pursuing a Masters degree while Salces is pursuing a doctorate degree. Javier, who is also the overall Project Manager of Birds-2, served as the Electronics PCB Designer of Maya-1 while Salces was responsible for developing the satellite's Ground Station Segment and Communication Subsystem.

The satellite which is classified as a 1U CubeSat measures 10 x 10 x 11.35 cm and weighs 1.11 kg (2.4 lb). Maya-1 took a year and three months to build using components which are commercial-off-the-shelf items and determined safe for use in space. The satellite, along with BHUTAN-1 and UiTMSAT-1, is equipped with Automatic Packet Radio Service Digipeaters. This equipment will be used to demonstrate communication relay capabilities of the three satellites. Maya-1 is also equipped with a Global Positioning System chip and a magnetometer, the latter be used in measuring magnetic fields in space.

Maya-1, along with the BHUTAN-1 and UiTMSAT-1 were launched to space on June 29, 2018 via the Falcon 9 Full Thrust rocket at Cape Canaveral in Florida as part of the SpaceX CRS-15 Commercial Resupply Service mission. Maya-1, along with the two other satellites were deployed from the International Space Station (ISS) on August 10, 2018 through the space station's Kibo module. It orbits approximately the same altitude of the ISS at about 400 km (250 mi). A few days after its deployment amateur ground stations from 10 participating nations of the Birds project have confirmed communication with the three satellites. Table 5, lists some of the properties and information regarding Maya-1.

Table 5.

Spacecraft Properties	
BOL mass	1.11 kg (2.4 lbs)
Dimensions	10 x10 x11.35 cm
Orbital Parameters	
Inclination	51.6°
Frequencies	
145.900 MHz	Downlink
437.375 MHz	Uplink

While built solely by Filipinos, the satellite is jointly controlled and operated by the Philippines, Bhutan, and Malaysia. The combined cost to build and launch Maya-1 was around $150,000. Figure 10, shows an engineering model of Maya-1.

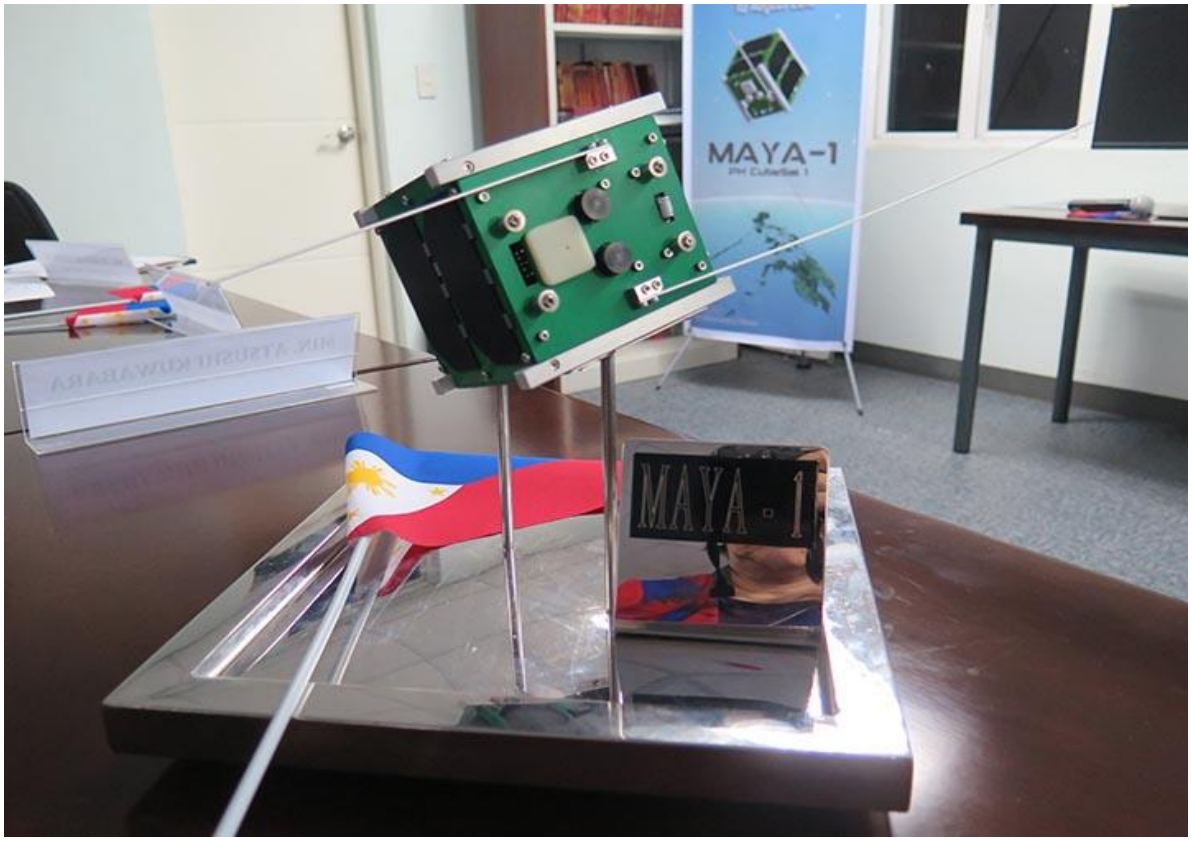


Figure 10. The Maya-1 1U CubeSat

The mission of Maya-1 is for "experimentally testing of commercial components" and due to its size, "a cost-effective educational platform" to help Filipinos build future satellites. The satellite could also be used to relay messages in the event typhoons render cellular services unavailable. The satellite expected operational and service life will be from about six months to about a year.

The Maya-1 is a nanosatellite-based remote data collection system called Store-and-Forward (S&F) and a digital messaging capability through Automatic Packet Reporting System (S&F). It will also conduct magnetic field measurements, test a low-cost commercial off-the-shelf Global Positioning System (GPS) receiver, and record single-event latch ups in orbit. It was turned over to the Japan Aerospace Exploration Agency (JAXA) on May 15, 2018 before it was launched to the ISS on June 29, 2018. Figure 11, illustrates the launch of the three 1U CubeSat.

Maya-1 carries two cameras: a wide-angle and a narrow-angle lens to capture images and minimum resolution videos for research purposes. It also has a Global Positioning System commercial off-the-shelf chip, as well as a magnetometer for measuring the magnetic field in space. Maya-1 is expected to last around nine months to a year. Telemetry data are now being received. The data-forwarder capability is slated to be operational as soon as enough separation between the Maya-1, Bhutan and Malaysian CubeSats are optimized.

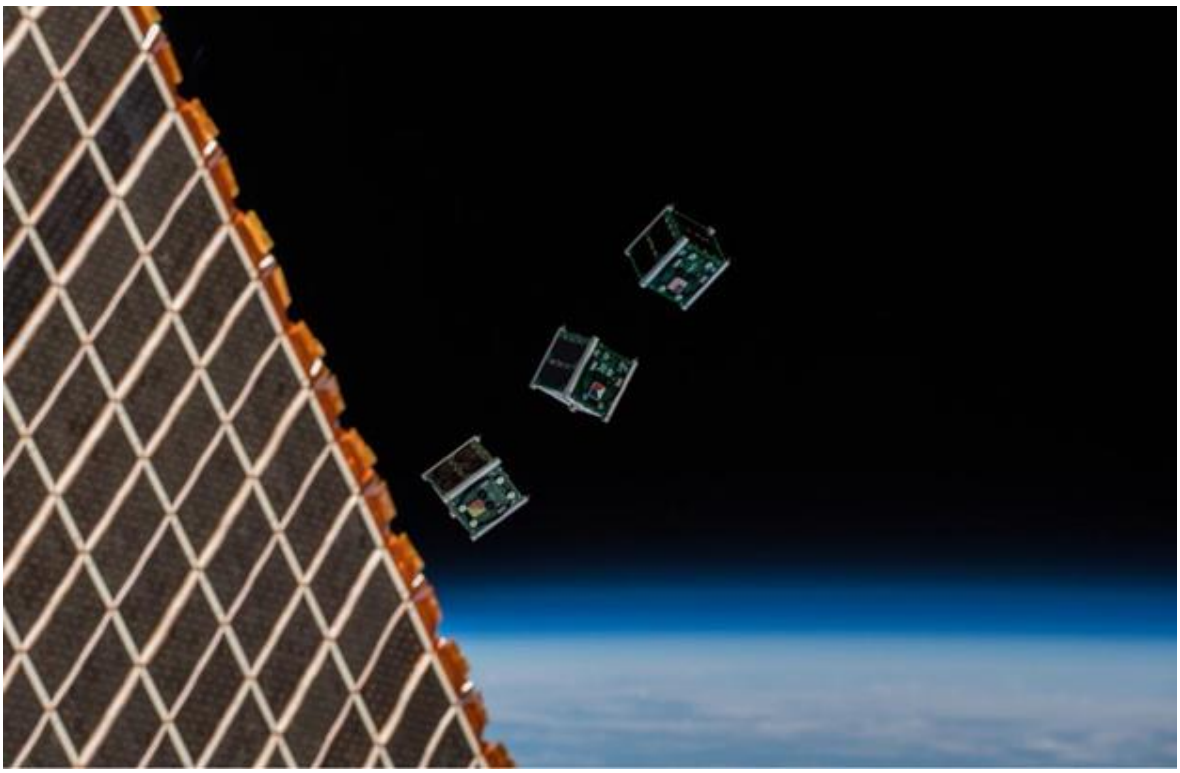


Figure 11. The launch of Maya-1, Bhutan-1 and UITMSAT-1

The Two Line Element Sets or TLE for respective BIRDS-2 CubeSats has been identified. Mike Rupprecht, DK3WN had already announced his results of the tracking on his blog. NORAD has confirmed the TLE. The latest TLE for the Maya-1 is as follows:

```
MAYA-1
1 43590U 98067PE  18228.77648787  .00010199  00000-0  15804-3 0
9997
2 43590  51.6396  76.7203 0006951  93.3359 266.8427 15.54649489
988
```

Maya-1 Two Lines Element Sets

University of the Philippines MicroSat Development Center (UPMDC)

The UPMDC is located in the main Diliman campus of the University of the Philippine in the National Capital Region. It will set to open sometime in December or early January of 2019. Figure 12, shows the new UPMDC which is also called University Laboratory for Small Satellites and Space Engineering Systems or ULyS^{3}ES. It is built to house the following:

- *Micro and nano satellite development center*
- *Small-satellite simulator system*

- *Development and Prototyping Rooms*
- *Full anechoic chamber test facility*
- *Amateur radio and satellite WXSAT/AMSAT ground station*
- *Graduate students' workstations*
- *Clean Rooms*
- *Administration office*

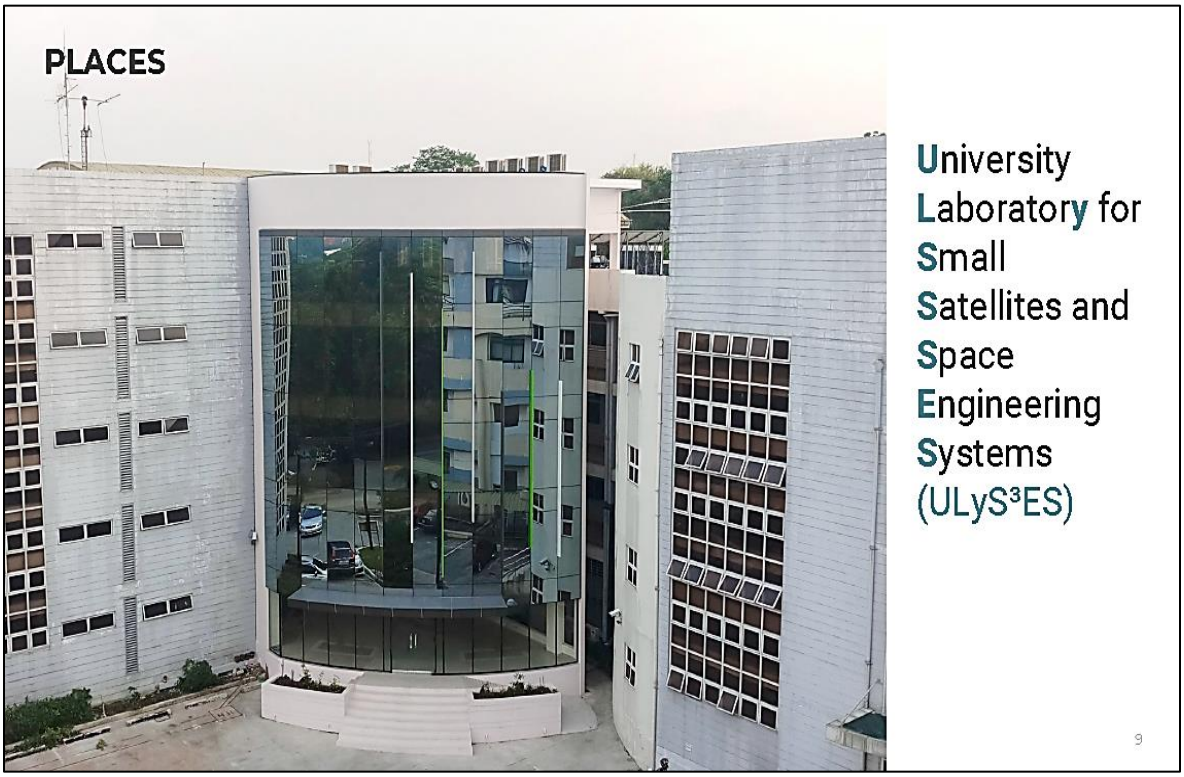


Figure 12. University of the Philippines MicroSat Development Center

Philippine Earth Data Resources Observation Center

Abbreviated as PEDRO, is a satellite ground station situated at the Department of Science and Technology–Advanced Science and Technology Institute (DOST–ASTI) facility at the University of Philippines Diliman in Quezon City, Philippines. It is part of the Philippine Scientific Earth Observation Micro-satellite (Phil-Microsat) program by the Department of Science and Technology, which includes the deployment of the Diwata-1 and Diwata-2 microsatellites. Besides, monitoring and controlling both Diwata-1 and Diwata-2, the PEDRO station shown in Figure 13, under the Phil-Microsat program, also receives information such as imageries from commercial satellites.

The project was originally aimed to develop the capacity to received, process and distribute data from multi-sensors throughout the Philippines and satellite imageries through the establishment of a multi-mission ground station (MMGS) facility. It involves setting up of a system and infrastructure that will securely receive process, exploit and distribute space-borne imagery and derive information from the supported remote sensing satellites for various applications such as disaster

mitigation, natural resource management, environmental monitoring, pollution control, energy exploration, intelligence, and emergency response management.

As part of its strong commitment in providing innovative solution through research and development, a Memorandum of Agreement between DOST and the Civil Aviation Authority of the Philippines has been signed for the establishment of a Remote Multi-Mission Antenna System (RMMAS). The ground facility is designed to communicate with Earth Observation satellites including micro and nano-satellites deployed in space by receiving, processing, exploiting and distributing space-borne imagery and derive information from the supported remote sensing satellites for various applications such as disaster mitigation, natural resource management, environmental monitoring, pollution control, energy exploration, intelligence and emergency response management. It will include a 7.3 Meter Tracking Antenna with Radome and a 40-foot container van which serves as the control room. The expected completion date of the RMMAS is by the end of 2018.

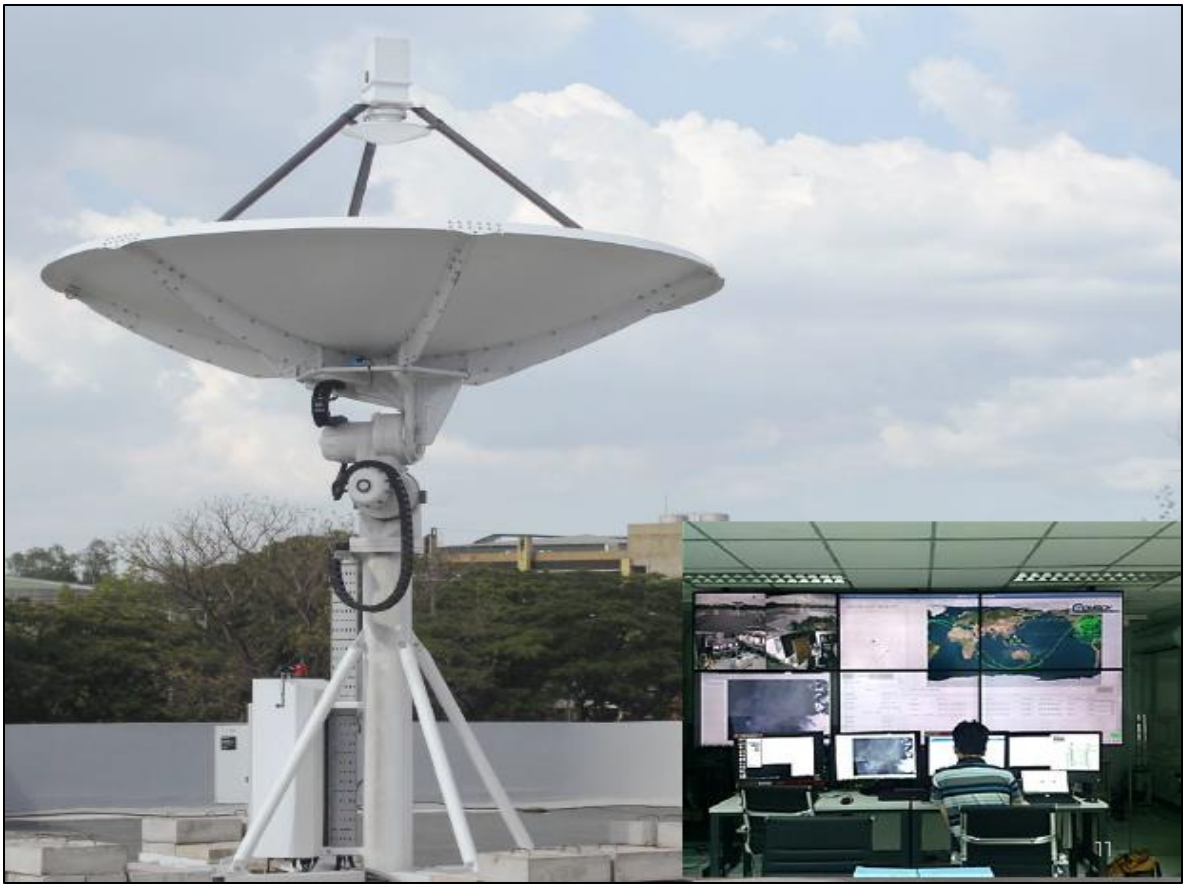


Figure 13. PEDRO Ground Station

Space Science & Technology Proliferation Through University Partnership

The University of the Philippines Space Science and Technology Proliferation Through University Partnership or STeP-UP was created and funded by the Philippines Department of Science and Technology as a University consortium on Space with five current and future participants. It is a four-year program to develop space and technology applications for use in university's STEM research, create a Masters degree program in nano-satellite technology and a prime mover for the

soon to be created Philippines National Space Agency. In addition, it will be the driver for many science and technology application development including disaster risk management applications. Figure 14, illustrates the STeP-UP program with the major activities as follows:

- *Class lectures on space science and technology to be conducted by EEEI faculty and graduates of Space Science Technology Application program*
- *Development of 1U CubeSats at ULyS³ES. A group of 8 students from this batch will develop, build and test one 1U CubeSat. The next batch of students will then perform the same tasks as the first batch, all at the end of their graduate studies*
- *Space environment testing of CubeSats (Engineering Model and Flight Model) at Kyushu Institute of Technology (Kyutech), Japan*
- *Short-term lectures to be conducted by Kyutech professors at UP EEEI*
- *Launch of the CubeSats via ISS*
- *CubeSat operations and four ground station development for data collection*

Figure 14. UP EEEI STeP-UP University Consortium Partnership

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A Digital Signal Processing Software Demodulator for Satellite Telemetry Using Brute Force Techniques

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Keywords: brute force, brute force demodulator, BFD, digital signal processing, DSP, 9600 baud, G3RUH demodulation, satellite, telemetry, RTLSDR

"When in doubt, use brute force."
-Ken Thompson, designer and implementer of the Unix operating system

Score one for Team Good Enough

It is often the case in computer science (and in life) that we need to solve some particular problem, and there isn't just one unique answer that works as a valid solution. There could be multiple answers that are all acceptable or close enough. For example, real world solutions to problems like turning the dial to tune in a radio station on shortwave, pointing an antenna for best reception, or adding sweetener to your morning coffee don't require an exact solution, just one that is "good enough." If you can hear the station clearly, the dial and antenna are sufficiently correct. For the mathematical versions of this class of problems, there are frequently formulas and approximations available that will give an answer that is "good enough" by using techniques such as successive approximations, least mean squares, stepwise refinement, or gradient descent.

In the case of the software based demodulator for G3RUH modulation, as long as the bit clock and bit rate are "good enough" we will correctly demodulate the packet. There are multiple similar correct solutions that will give the same valid packet. For example, the demodulator could be making the decision of whether the currently received bit is a one bit or zero bit just a little tiny bit[8] earlier or just a little bit later than optimal and everything will still work correctly.

In some cases it is desirable to get a correct answer even if it takes extra effort. Receiving satellite telemetry is one such case, particularly on a low elevation pass with weaker signals. Usually the data from the satellite will only be transmitted once, so we want to do everything we can to correctly demodulate the data packet even if that means taking extra time and effort. For G3RUH demodulation, there are only a few variables to consider and they have a limited number and range of values that they can accept. If we know that the signal is a 9600 baud signal, then the real baud rate must be very close to 9600.00 baud. We can probably bound the baud rate value to be between 9598 and 9602 baud (or so) with high certainty. The phase at a particular moment in time could be any value between zero and 359.9 degrees.

Moore's Law and increasingly faster networking speeds have yielded computer and processors that have advanced to the point where calculations that were once not even considered are now easily performed. For example, it was once considered totally impracticable to search every computer on the public Internet by making a network connection to every one of the over four billion possible IPv4 address. But, researchers are now scanning the entire Internet for their research projects.[9] It's now possible to complete a scan of the entire Internet in under five minutes.[10]

It is often the case that we want to try to solve the problem efficiently using as little computing/processing power as possible. Everything else being equal, if one method takes very little time and another method takes several days, then we probably want to use the quicker method. For example, when using a laptop or cell phone, efficiency could increase battery life. But on a computer connected to the AC power mains we don't need to worry about battery life. However, if the difference is only a few milliseconds between the quicker and slower methods, then we might not even care. And we don't always need to be optimally efficient to be quick. A modern CPU is fast enough that a human will not even notice the extra processing. In fact, for some problems we can just try all possible values for all of the variables and see if any of them give us a valid answer. This is the Brute Force Demodulator (the "BFD"[3]) approach.

The Brute Force Demodulator (a.k.a. "The BFD")

As an example, let's consider the 9600 baud G3RUH AX.25 packet software modem. Specifically, let's look at the demodulator. The demodulator is usually looking at the audio output from a radio receiver, which we presume contains a radio signal representing a valid bit stream from a remote transmitter. In order to recover the bit stream, the 9600 baud G3RUH demodulator needs to correctly determine two things: when is the right time to decide the value of the current bit being received, and, at that instant, is the bit is a zero bit or a one bit[2]. The timing has to be decided about 9600 times a second, but there actually is an optimal instant in time to make the decision (the optimal time is when the eye is open widest) but we don't know ahead of time exactly when that optimal instant is. However, if we pick moment in time that is "close enough," when the eye is open "wide enough," then we will still get the correct answer for whether this is a one or a zero bit. Many demodulators use a local clock running at 9600 Hertz which is then adjusted using some scheme based on the input signal.

The bits might be arriving at "about" 9600 baud. The 9600 baud clock of the transmitter might be slightly off frequency, and/or his digital to analog converter might be off, and/or our own analog to digital converter might be slightly askew and/or there might be Doppler. As seen by our demodulator, the bits could be arriving at 9599.9 bits per second or 9600.1 bits per second or some other nearby value. In any of these cases, if we were to blindly make the bit decisions at a fixed rate of exactly 9600.000 bits per second, then rather quickly we will start seeing bit errors because we are no longer deciding near the optimum moment in time. That is, our clock is "slipping" compared to the transmitter's clock and the two clocks will only align briefly with each other some of the time. The usual solution for a demodulator is to adjust the local clock repeatedly to keep it in synchronization with the transmitter's clock. For example, one approach for solving the clocking problem is to look at the received waveform and see if we are deciding the bit a little bit early or a little bit late or at just the right

time[4] and then giving our local clock a nudge in the right direction. Another clocking approach is to model the bit clock as a phase locked loop (PLL) and adjust the PLL slightly on each received bit until we achieve "lock." Both methods are relatively simple, work well, and involve only minor calculations. But if we change the local clock too much (or not enough) then we can cause bit errors by deciding at the wrong instants.[15] If the demodulator does decide incorrectly (only one time), it could also go back and assume the weakest valued bit was the wrong bit, flip it, and try checking the CRC for the packet again (with that one bit changed) just to see if that fixes everything. Some software demodulators will do this. However, there's another simple approach: brute force.

Just try every possible value. If it's in there, we'll find it.

Brute force is a method that doesn't use any intelligence, but just blindly tries solutions until it finds the answer. Brute force safe crackers would try every possible combination to the safe ("left zero, right zero, left zero", then "left zero, right zero, left one", and so on). Brute force password programs can try every possible eight letter password, for example, starting with "aaaaaaaa", then "aaaaaaab", then "aaaaaaac", through "aaaaaaaz" to "aaaaaaba" and so on. Computers are really good at this sort of thing, and they can do it really fast.

Using brute force for a demodulator is not a new idea, but the idea has not received as much attention as other methods. In the brute force approach for a software G3RUH demodulator, the demodulator just tries all possible values for the bit clock frequency and phase. Actually, we don't have to try every possible value. As soon as a combination is found that yields a valid bit stream we can stop. We can also speed up the work by trying the most likely values first and then try the less likely values, or for a continuous signal we can try the values that worked last time and if they don't work then try all possible values.[12]

In the brute force demodulator approach, the demodulator tries multiple bit rates and only makes the assumption that the exact bit rate, whatever it is, is fixed for the duration of the AX.25 frame that it is trying to demodulate. For a software modem we can implement a brute force approach in a couple of ways. By analogy of a depth-first-search, if we have buffers full of samples, then we can try a particular frequency/phase starting "here" at this sample and see if we get a valid frame. If not, increment the frequency (or the phase) by a small amount and try again on the same buffer of samples until you either see a valid frame or until you have tried all possible values (which is what will happen if there's just noise being received). In the latter case, advance forward in the buffer by some number of samples (or onto the next buffer) and start over.

For example, for 9600 baud G3RUH, we could try to demodulate AX.25 frames by creating a single demodulator and starting with the bitclock phase at 0 degrees, and the baud at 9598.0 bits per second. If we don't get a valid packet then we start over, incrementing the bit rate slightly and try again on the same incoming samples. Keep incrementing until we get to, for example, 9602.0 baud, and then if we still don't have a valid AX.25 frame we can increment the starting phase by a few degrees and try all the possible baud rates all over again. Keep going until all possible phases have been tried or until you have a valid packet. Alternatively, we could implement multiple demodulators all running in parallel

(think: breadth first search) and send each digital sample to all the demodulators until one of them finds a valid frame at which point we reset all the demodulators. The breadth first search has the advantage that all of the demodulators run at the same time, they are all looking at the same sample, and we don't need a buffer of samples or buffer management of the incoming samples except for the current sample.

In the C programming language, a struct for defining a single demodulator might look like this[17]

```
struct demodulator {
   double  clockfreq;       // nominal clock frequency (near 9600.0)
   double  startclockphase; // zero to 2-pi (or 0 to 360)
   double  clockphase;      // current clock phase
   double  phaseinc;        // phase increment for this clock frequency
};
```

We can declare a single demodulator, call it "dem," using the above struct. This demodulator has a fixed clock frequency near but not exactly 9600 baud, a starting clock phase (zero to two pi, although you could just as easily use zero to 360 degrees), the current phase of the clock and the phase increment amount to be used at this clock frequency (stored so that we don't have to recalculate it on every sample).

Just a easily, we can define a hundred (or even a thousand!) software demodulators as an array of dem[] and then initialize all of them as such

```
i = 0;
for (j=BAUD_LOW; j <= BAUD_HIGH; j++ ) {
   for ( k=0; k < CLOCK_PHASES_PER_BAUD; k++ ) {
     dem[ i ].clockfreq = j;
     dem[ i ].startclockphase = (M_TWOPI / CLOCK_PHASES_PER_BAUD) * k;
     dem[ i ].clockphase      = (M_TWOPI / CLOCK_PHASES_PER_BAUD) * k;
     dem[ i ].phaseinc        = ( j * M_TWOPI ) / samplerate;
      i++;
   }
}
intTotalDems = i;
```

then as each new "current sample" arrives we look at each demodulator, increment the current clock phase using the phase increment amount. If the current clock phase just went over two pi (or over 360), then it is time to decide the bit, otherwise there's nothing to do yet.

```
while "there are still more samples" {
   for ( z = 0; z < intTotalDems; z++ ) {
      // get the address of the current demodulator
      p = &dem[ z ];

     // increment the clock for the current sample
      p->clockphase = p->clockphase + p->phaseinc;

     // Is it time to decide this bit?
```

```
      if (p->clockphase > M_TWOPI) {
            p->clockphase = p->clockphase - M_TWOPI; // reset it
            if ( currentsample >= 0 ) {
               currentbit = 1;
            } else {
               currentbit = 0;
            } // else
      } // if
   } // for
} // while
```

Now, in actual 9600 baud AX.25 we still have to save the currentbit and unscramble the bits, undo the NRZI encoding, build up the current byte and check for HDLC flags, undo the zero bit stuffing, and start building the AX.25 packet frame.[1] If there's a valid signal present, then sooner or later one of the demodulators sees the second HDLC flag. We check the CRC and if it is a match then we output the valid AX.25 frame, reset all the demodulators and start all over again.[16] It's important to note that the demodulator that gets a valid frame might not be deciding at the optimal time, but it's good enough that we decided all of the bits correctly and we got a valid CRC. We only need to receive this packet once. As long as it's been verified as a valid frame, it doesn't matter if the solution was not optimal or how much computing power was expended. We got the right answer.

But, some people might say, that's a lot of wasted computations. There are more efficient ways that would use fewer CPU cycles. Perhaps, but were you really doing something else important with those CPU cycles? Probably not. A modern computer will be running with a clock speed over 2 GHz with (at least one) quad core CPU. On a single quad core CPU that's "about eight billion" CPU instructions per second. The above calculations take a few hundred, perhaps a few thousand machine instructions per demodulator leaving over seven billion machine instructions per second left over for other uses. Most modern CPUs actually spend most of their time idle doing absolutely nothing unless the CPU has purposely been configured to be kept busy with a background task like video transcoding or a BOINC project such as SETI@Home.

Brute force uses more CPU power, more time, and more electricity, but if it's in there, we'll find it. Is it efficient? No. Does it give the right answer? Yes, and more often than some other software demodulators. Is this the be-all-and-end-all of software modems? Actually, it's not. There is still other processing that can improve the performance. The incoming audio still needs to be filtered to remove noise added by the receiver and the communications channel, and the receiver could do a better or worse job. The receiver itself could be mistuned, which on an FM receiver may or may not result in a DC offset of the signal that might need to be corrected. In addition, the actual frequency of the transmission could change if the transmitter is drifting (or changing due to Doppler). In addition, there could be more than one transmitter on the same channel (think: APRS) which will require the receiver to re-synchronize on potentially every received frame. (It is left as an exercise to the reader to determine whether or not a collision, that is, two stations transmitting at the same time, can be undone by subtracting one received signal from the combined received signals leaving only the second signal.) Other noise or interference on the channel could be characterized and notched or digitally subtracted.

And all of this work is just for a single demodulator for a single channel. In the future, a wideband software defined receiver could do signal classification to identify the types of data signals being received and then create dozens or even hundreds of different software modems to receive and demodulate many different types of signals simultaneously.[5]

Next time you have recording of a signal where you know there's a signal in the recording, but you can't demodulate it correctly, consider trying brute force techniques.

Footnotes

1 For a good discussion of all of the lower level details of AX.25, particularly with respect to Bell 202 modulation, but also applicable for 9600 G3RUH AX.25 see
Finnegan, Kenneth W. and Benson, Bridget, PhD. "Clarifying the Amateur Bell 202 Modem." 33rd ARRL and TAPR Digital Communications Conference. 2014. Also available at
https://www.tapr.org/pdf/DCC2014-Amateur-Bell-202-Modem-W6KWF-and-Bridget-Benson.pdf
In addition, there's some good technical documentation and C code that does all of the low level AX.25 packet work in Moe Wheatley's KS12V10 software at http://www.moetronix.com/ae4jy/projects.htm.

2 If we were considering a PSK demodulator, or a G3RUH 9600 signal from a wide bandwidth RF receiver like an RTLSDR dongle rather than the audio from the discriminator, then we would also need to brute force the solution to the carrier frequency. To keep the example simpler, in this paper we just consider the filtered 9600 baud audio signal which does not need to worry about the RF carrier frequency. The constructing of a signal classifier to watch multiple megahertz of received RF from an RTLSDR dongle[7] for multiple 9600 baud signals at arbitrary (and Doppler-shifting) frequencies from different transmitters, demodulate and then brute force each one is left as an exercise to the motivated reader with an excess of disposable free time. The author would appreciate a copy when it's finished. Interested programmers should contact the author.

3 To be clear, the acronym "BFD" as used here is the "Brute Force Demodulator." It is not a municipal Fire Department, nor should it be confused with other popular culture BFx acronyms such as the "BFG", which depending on your age and background is either a fictional giant by author Roald Dahl or a weapon from the computer game Doom. Neither is "BFD" related to "BFM", which is both an acronym from quantum field theory and also a special kind of black magic. Nor is it related to the "BFR", a SpaceX rocket, nor to the "BFB", a really large burrito from a local Mexican restaurant. But I digress…

4 Recovering the clocking rate using this method is usually called early-late gate timing recovery but it might be more memorable as the Goldilocks approach ("This clock is too fast; this clock is too slow; but this clock is just right.") It is relatively simple and it works well. Call it early-late gate or call it Goldilocks, just don't call me late for the satellite pass. Time, tide, and orbital mechanics wait for no one.

5 Imagine running one program to look at all of the HF bands during Field Day or CQWW and having it show you all the CW signals, all the PSK31 signals, all the FT8 signals, all the RTTY signals, all the slow scan pictures and having it performing speech recognition on the SSB signals[6] to show you all of their callsigns. Additionally, it should tell you which stations you've already worked in this contest and

prioritize which ones you should work next for maximum point values. Today, CW Skimmer can receive multiple CW signal within the receiver bandpass and simultaneously demodulate all of them, however it only demodulates the CW signals. Imagine the same sort of thing, but simultaneously for all bands and all modes including voice.

6 Hint: A general purpose English language speech-to-text engine is not needed here. We just need someone to write a speech recognition engine that recognizes ITU (and DX) phonetics and then runs the results through a super regular expression to check for "CQ" and valid amateur radio callsigns. Interested programmers should contact the author.

7 Of course, the ultimate version of this receiver has an array of multiple high-speed wide-bandwidth receivers (such as the RTLSDR dongles) which can have their received digital signals arbitrarily phased together allowing simultaneous reception of multiple satellite signals (and demodulation of multiple different types of signals) with all of the advantages of phased arrays (such as a lack of moving parts, directional gain, target tracking, putting a null on the unwanted signals, reprocessing the same data phased differently for different targets, and so on). And, oh yes, I think you can track multiple amateur radio satellites at the same time and it can be done today. For an example of a RTLSDR phased array that uses four RTLSDR dongles, that tracks multiple GPS satellites, and that does not need any hardware to synchronize the dongles, see https://www.gnuradio.org/wp-content/uploads/2017/12/Wil-Myrick-GPS-Beamforming-with-Low-Cost-RTL-SDRs.pdf and then watch his YouTube video from GRCon17 at https://www.youtube.com/watch?v=IsmCQs5KVCs.[18] Now we just need to do a similar project for the amateur radio satellites. Interested programmers should contact the author…Hey, don't look at me like that. It's only software.

8 Pun intended.

9 Heninger, Nadia. Durumeric, Zakir. Wustrow, Eric. Halderman, J. Alex. "Mining Your Ps and Qs: Detection of Widespread Weak Keys in Network Devices." https://factorable.net/weakkeys12.extended.pdf

10 Your mileage may vary, some restrictions apply.[11]

11 "On a computer with a gigabit connection, ZMap can scan the entire public IPv4 address space in under 45 minutes. With a 10gigE connection and PF_RING, ZMap can scan the IPv4 address space in 5 minutes." See https://zmap.io/ for details. This could be useful the next time your ISP changes your home IP address while you're away on vacation.

12 Karn uses this scheme in some of his BPSK software demodulators including his demodulators for ARISSat[13] and ACE[14].

13 http://www.ka9q.net/bpsk1000.html. See the section on "Tracking and demodulation".

14 http://www.ka9q.net/code/acedemod/. See the section on "Offset Searching".

15 Possibly the demodulator decides incorrectly too many times and even the forward error correction (FEC) can't fix it up in post analysis. You ***are*** using forward error correction on your satellite downlink, aren't you? If you aren't using FEC on your digital satellite downlink, then you're doing it wrong!

16 Sometime random noise looks like an AX.25 packet. You only need some noise that looks like an HDLC flag, then a little later some more noise that also looks like an HDLC flag. Usually the noise before the second HDLC flag will not demodulate to a valid CRC value, but about one of every 65536 times, just by dumb luck, it will. These "packets" almost always look like complete garbage, particularly the callsign fields, so they are easily filtered and ignored if you are looking for satellite telemetry from a known callsign or set of callsigns. This "false frame" problem isn't unique to software modems, but it is more common with brute force techniques than you would see otherwise.

17 If there's interest in the C code for the G3RUH brute force demodulator, I'll put it up on github or some other open source code repository. Where do you think it should be published?

18 My thanks to Michelle Thompson for pointing me at these references when I half-remembered them and then couldn't find them again.

An Amateur Radio Satellite Easter Egg in *The Terminator*

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Recently I was re-watching the 1984 classic movie "The Terminator." In various scenes throughout the movie they try to impress the viewer with “futuristic” (well, futuristic for 1984) computer generated images and screenshots that contain, for example, 6502 assembler listing and other technobabble which are supposed to represent what the Terminator thinks and sees. Many of these special effects were more impressive looking back in 1984 than they are today.

A few minutes after the one hour mark, right after the spaceship turns left, you can see more computer generated columns of numbers for just a fraction of a second. However, this isn't 6502 assembler code. It's a listing of columns of numbers. A closer look shows that the column headers: Osc 8, RS-5, RS-6, RS-7, and RS-8. These are the amateur radio satellites Oscar 8, and the Russian satellites RS-5, RS-6, RS-7 and RS-8! The column numbers are UTC times and the longitudes for the equator crossings (EQX). Long time AMSAT members will fondly remember these listing as being used with an Oscar Locator to determine when a satellite would be visible above your local QTH by using the time and longitude where the satellite crossed the equator. Remember, the movie was made in 1984 and many amateurs would not yet have access to a personal computer to perform predictions using Keplerian elements.

For a look at the UTC and EQX listing, you can check this Youtube video (use the link to jump to the right part of the movie). It's only on the screen for a small fraction of a second. Don't blink.[1]

Photo 1 – a screenshot from the movie “The Terminator”. The wavy moire pattern at the top of the photo is actually visible in the movie.[2]

If you have a copy of the DVD of the movie, the timestamp will be a few minutes past the one hour mark. On the YouTube version of "The Terminator" this is the scene that starts at about 1:09:28. You can click on Settings, then Speed, then 0.25 in order to slow down the movie to more easily see the EQX listings at about 1:09:38 (or 1:09:39). This link will get you very close.

https://youtu.be/s7_qI6_mIXc?t=4168

Now, for those with too much free time, the questions are:

- What date(s) would these listing have been the satellite EQXs for?
- Were these EQX values calculated or just copied from a publication (QST perhaps?)
- Who was working for the special effects department that also knew about amateur radio satellites that inserted this Easter egg?

and

- Is there some obscure pun relating the equator crossing times of the satellites to the title of the movie and to the Earth's day-night terminator?

To get started on the first question, we first need to know the NORAD IDs for each satellite. Oscar 8 was NORAD ID 10703. RS-5 was 12999, RS-6 was 13002, RS-7 was 13001 and RS-8 was 12998. Historical archives of the satellite Keplerian two line elements (TLEs) are available from Celestrak.com via a special request form at

https://celestrak.com/NORAD/archives/request.asp

Note that for the first column, for Oscar 8, the UTC times are only a few minutes apart. The times cannot be times for subsequent orbits. Each line must be for the next day or a few days later.

If we obtain the historical TLEs then we can try to compute the EQX times. Experience has shown that if you want to reproduce historical results, then it is best to use the hardware and software of that historical era if at all possible rather than re-running the calculations with modern software programs on modern hardware. In the latter case, you might get correct but slightly different answers. And if the original calculations had errors, you likely won't reproduce them with the modern (now fixed) hardware and software.

However, you will find quickly that the software written in the 1980s has some challenges running on a modern operating system. Trying to run ORBITS.BAS under GWBASIC doesn't even get started (GWBASIC.EXE will not run under a modern 64-bit Microsoft Windows) and neither would the BBCBASIC emulator that I had used previously to run a modified version of PLAN13.BAS. These had been working fine (years ago) when I had been using a machine with Windows XP, but probably an emulated older version of Windows will be needed to pursue this further. Interested orbital mechanics archeologists should contact the author.

If you have further information on how this got into the movie, or other suggestions for calculating the dates for the EQX times, please contact the author.

Footnotes

1 "Don't blink." Just some advice from the Doctor.
2 https://xkcd.com/1814/

Taking the Classroom to Space via Amateur Radio with the ARISS Program

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AMSAT Symposium 2018
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What is ARISS

The Amateur Radio on the International Space (ARISS) Program is a wonderful and exciting way to introduce Amateur Radio to the next generation and the current generation via our schools and educational organizations.

Working with the School

If you already have a child or know somebody who has a child in school or an educational organization reach out and send information via the student or school to a math or science teacher, a librarian, a principle, or the board of education. In some cases, you may already know a teacher or discover who in a school organization might take the lead for an opportunity. If there is any interest you will get an immediate response. If you do not get a response, then maybe the information did not reach the right person in the school to generate the excitement or there may simply be no interest. Some schools may not have time in their busy schedule for extra activities. The goal is to reach out and identify the champion in the school who will take the information, generate the excitement, and make it happen.

In the case of one school, I found the principle and the librarian immediately latched onto the idea. This made it so much easier, because the school took the lead and jumped on building the proposal with a strong educational plan around the topic of STEM (Science, Technology, Engineering, and Mathematics). There was so much excitement initially that it was clear this school was dedicated to submitting a successful proposal. They submitted their proposal and secured the opportunity for their students to ask question directly with an Astronaut on the International Space Station (ISS).

The Proposal Process

The Proposal Process is where it all begins and it might seem like a big challenge. The ARISS team has a website, www.ariss.org, packed with a planning guide, online webinar schedules, and material to help you build a strong educational plan for the proposal. It takes some work by the school to develop an educational plan for their proposal. The involvement by the Amateur Radio team will come later in the process if and when the need for an Equipment Plan is required.

For planning purposes you can expect about 12-18 months from the beginning of the process until the actual event where the students communicate with an Astronaut aboard the ISS. While this may seem like a lengthy period of time you will learn that it is a learning process from the beginning to the end. A lot of questions and actions that may not be obvious in the beginning will start to make sense throughout the process.

After the close of the proposal window it takes about 6-8 weeks to learn if your proposal was accepted or not. If you have been chosen you will participate in an ARISS Orientation Session and paired up

with an ARISS Technical Mentor to help develop an Equipment Plan.

The Equipment Plan

You may chose the Telebridge Link or the Direct Link for your ARISS contact preference.

Telebridge Link

The Telebridge Link offers the opportunity for schools who have no Amateur Radio Operators or equipment readily available to use for a direct radio contact. The telebridge link offers a wider range of options for the ARISS committee since there exists a network of dedicated Amateur Radio volunteers around the world who can link their radio station via a telebridge. The means the school can still talk with an Astronaut even when they are not located directly overhead. The ISS only needs to be in range of the telebridge station. There are times when the ISS may not be not directly in range of a school during normal school hours. This problem can present a challenge for a direct link, but the telebridge allows the ARISS team to work around this obstacle. It does not require any radio equipment at the school, just a direct telephone link that does not go through a switch board.

Direct Link

The Direct Link contact requires Amateur Radio equipment and antennas to be installed at the school. This puts the burden upon the Amateur Radio team to install and test the equipment before the event. I prefer the Direct Link because it allows you to demonstrate the antenna and radio automation so the students and the crowd can see the radio equipment being used in action. It provides a sense of simplicity to the crowd in that they can also do the same thing at home with a radio and an antenna.

The number of radio contact opportunities are limited when electing the Direct Link method, because the ISS must be in range of the school during the hours the school can support for the radio contact.

The ARISS team has a set of recommended requirements for a Direct Link contact. While the equipment list may seem overwhelming if this is your first time, you should understand the recommendations are designed to insure complete success all the way down to the backup station equipment requirements.

The recommended Primary Station consists of the following:

- Transceiver 50–100 W output, 1 kHz tuning steps, and 21 memories capable of storing split frequencies
- Low loss coax (such as 9913 or LMR 400)
- Mast mounted receive pre-amplifier
- 14-element yagi antenna with switched circular polarity
- Antenna rotators for azimuth (0–360°) and elevation (0–180°), with interface for computer control
- Computer with tracking software for antenna control (including flip mode operation)

Building a Team

Pulling a successful team together can generally be a daunting task in any area of life. I have found the Amateur Radio community to be very supportive of anything related to communicating with the ISS. Volunteers generally appear for these ARISS events when you need help. Local Amateur Radio clubs always have several members who will appear when you need them most. I encourage everybody to reach out to all of the area Amateur Radio Clubs and get them involved and give them credit even if only one member shows up. Praising all participants goes a long way when you need help even if they only show up for moral support. You never know who is going to get excited about what you are doing. Plant the seed, foster it, and let it grow. It is also exciting to meet radio club members from other organizations, share stories, and learn something along the way.

Two of the three ARISS events I supported with radio equipment were located 100 miles away from my home. These logistics dictated more attention was required for details and planning. The sites had to be surveyed, but I discovered I could rely on people local to the area of the distant school to go out and take a look to see how the radio horizon looked and if there were any concerns for mounting the antenna. This generally consisted of pictures around the school and pictures taken in different directions from the school rooftop where the antennas might be located. I also utilized Google Maps to survey the site to get an idea of what to expect before hauling the radio equipment and antennas to the school site 100 miles away. If I forgot something, there would be no hope in turning back the same day.

The site survey requires identifying a few basic things:

1. Where the antennas can be mounted
2. How can the antennas be mounted and secured
3. How far does the cable need to run from the antenna to the radio equipment
4. How will the cables be routed from the roof to inside the building
5. How far are the electrical plugs from the radio equipment
6. Where are the circuit breakers located
7. Any obstructions that could block signals at the antenna (water towers, hills, buildings, etc.)

Setting up the Equipment

The area that requires the most help and support is setting up the equipment and disassembling everything when you are done. My first ARISS setup required manual labor and a ladder to climb up two separate rooftops. There can be legal or insurance related issues as well. This may require you to sign some paperwork authorizing access to the rooftop and it may be limited to a few people. In other words, there are rules and in one case the school had to temporarily add me to their insurance list for coverage before I could access the roof. Basically, the school librarian, the maintenance person, and I were the team to carry everything up to the roof, then to another roof, and assemble it. Carrying two awkward sheets of 4' x 8' plywood up on the roof along with everything else can drain your energy quickly.

This exercise is quite different than setting up satellite antennas on Field Day on the ground right beside the trailer instead of climbing up on a roof. If you have already been exercising emergency preparedness for Field Day every year, the station setup becomes much easier. It is always comes down to how you mount and secure antennas at a school and route cables that present a challenge. Every school is different.

Securing an antenna on a rooftop can be a challenge. I chose to utilize a 9 foot Glenn Martin Rooftop tower attached to a 4' x 8' sheet of 5/8” plywood. An additional sheet of plywood was placed

underneath this to avoid the bolts securing the tower from gouging a hole in the roof. The roof at all 3 schools I supported had a flat roof or a reasonably flat. There was nothing available to secure the antenna and it would not take much wind to topple the tower. Our ARISS Technical Mentor suggested using 5-gallon buckets and fill them on the roof with water. So, we decided to use 10 5-gallon buckets at about 48 pounds each to sit on the 4' x 8' sheet of plywood. This made the antenna system stable and it withstood recorded winds up at least 55-60 MPH. A new problem developed at the second ARISS event when the temperatures dropped below freezing. If the water in the buckets froze, we might lose the buckets from cracking. We had to find a suitable solution to prevent the water from freezing. This could be as simple as adding salt or antifreeze. Depending on your method you might need to take environmental precautions when disposing the water, opposed to pouring it in the downspouts on the rooftop. On the other hand, if it is hot outside, you might need to replenish water that has evaporated. An alternative would be sandbags or concrete blocks, but they will require more labor The bucket method was chosen due to simplicity of filling the lightweight buckets on the roof and pouring out the water before bringing them back down from the roof.

A big lesson was learned by the time setting up an ARISS station came around for the second and third schools. One of your best friends may be waiting for you to ask for help. Those big red fire trucks with bucket lifts and ladders are a real benefit if you get the opportunity to gain access to them. What a huge difference the local Fire Department can make to help simplify and remove the muscle power required to install antennas on the roof. The school officials contacted their local Fire Department requesting help and their teams were eager to help the school. These organizations are an incredible asset and welcome anytime they can help lift equipment onto the roof. Especially, when the rooftop is 40 – 60 feet above your head. I cannot praise and thank the participating Fire Departments enough for their generous support. Their teams were there to raise and lower the antennas when we needed them the most. Reach out to your local fire department if you need help with antennas to support an ARISS event. Tell them what you are doing, invite them to observe the event, feed them, and thank them in front of the ARISS event crowd. These teams allowed us to quickly concentrate on the technical setup opposed to being physically drained for the day. It was also a fun experience riding in the bucket truck and climbing up and down the long extension ladder on the truck.

When the parents and the school staff start to see any activity on the schoo; rooftop, they are always interested in what is happening. They start asking questions. One of the most advantageous times to be on the roof and making the antennas move is during the time school is about to dismiss the students for the day. The parents are in the pickup line watching everything you do, the students are looking up from their buses, and the school staff is watching. I try to add to the excitement by making the antennas move when there is a crowd watching. This starts a lot of discussion about what is happening on the roof and it makes for great advertising. I never realized this until I got off the roof one day and people were asking what I was doing on the roof.

Testing the Equipment

It is important to understand your station setup. This means you need to run practice exercises to make sure everything is working 100%. If not, fix it before the event. These practice sessions should include the students so they know what to expect before the event. Line them up and simulate the experience with another operator using a handheld to act as the astronaut aboard the ISS. This can be a fun exercise and prove to reduce any anxiety concerning what to expect. It really provides feedback about the audio system in the building and if there are any feedback, distortion, or hum that needs resolved.

Audio isolation transformers are helpful when hum on the audio is a problem. Another helpful hint is

the wireless microphone do not have this issue. We encountered this problem at the last minute during my first ARISS exercise and I remembered seeing some wireless microphones. When I discovered the microphone was removable and you could plug in an external audio source to the wireless transmitter, I immediately plugged it into the audio multiplexer at my radio and the received audio was hum free for the crowd to listen over the public address and sound system..

Noise Interference

There can be unexpected things that arise in the station setup process. Do not overlook the possibility of interference throughout the day. Rotate your antenna system 360 degrees and observe any noise interference and the direction from where it is located. Identify any objects or terrain that may obstruct a radio signal and note the direction. When you have received the date and time for your scheduled contact make sure you test the station by checking the frequencies you will be using and guide the antennas through that flight path to observe any potential interference.

During the testing phase of our equipment at Pinson Valley High School we identified some strong noise from the direction the ISS would be traveling for the event. The noise was so significant that it could interfere with the ISS if the received signal was weak. A team of dedicated volunteers in the Birmingham, Alabama area went out to the school and identified the source of the noise to be located at an electrical substation 1.5 miles away from the school. A quick call to to the Alabama Power Company received prompt attention. The power crew found a problem at the substation that could have effectively caused a potential power outage in the area. They promised to reroute power to take the substation offline on the day of the scheduled ARISS event. Alabama Power rose to the request and helped avoid a potential problem.

The Day of the contact

Needless to say everybody will be a little nervous on the day of the ARISS event even if you have planned, tested, and exercised all that you could possibly do. Check out your station one last time before the event to make absolutely sure everything is working as it should.

It could be a major disappointment when you have 1000-1500 people and some local or state dignitaries packed inside an auditorium or gymnasium and you hear nothing. In fact, you will experience this same fear when first attempting to establish communication with the ISS and there is no immediate response. There will be total silence in the room. Anxiety will take over your entire being. You will look at every knob and control 100 hundred times within a split second to be sure everything is set correctly from the computer software to the antenna controller and the radio. Relax, you probably started calling before the ISS was in range in anticipation of taking full advantage of the limited time you have. There may be 15-20 students who are lined up eagerly waiting for that once in a lifetime opportunity to ask their question directed to an Astronaut floating in space as they are about to pass overhead. Your goal is to make sure no child is left behind and the clock does not stop ticking.

Another trick I learned in the process was to start calling before the ISS is in range knowing there is no possible way they can hear you unless the signal is ducting or bending. This tends to build excitement with the crowd in anticipation for the response. You can hear a pin drop at this point because the audience already does not believe anybody is going to possibly respond from space. When that first clear response is heard you will hear sighs of relief and you will also be thankful somebody is on the other end to answer the call from space.

During my first ARISS event we lost about 40 seconds of talk time due to an antenna controller going into the flip antenna mode. We called the ARISS crew and we heard them respond in the static as I watched my antennas turning in the opposite direction right before the acquisition of signal. Then, the elevation rotor flipped the antennas 180 degrees. I was not expecting this to happen and I almost took over the antenna controls manually until I realized it was normal. The antenna controller was doing exactly what it was programmed to do. I did not anticipate the antennas moving at the last moment before the acquisition of signal. This was unexpected and it wasted talk time and created an extraordinary amount of anxiety. We were live and I was trying to figure out what was happening. Just about the time I was about to lose my composure, the reality hit me that we had to wait for the antennas to stop moving even though the ISS was clearly in range. I chalked this up as a lesson learned. Thus, I programmed the tracking software to start tracking objects when they are 25 degrees below the horizon. This way, we would not have to wait for the antenna to start tracking the ISS in the future after it was above the horizon. I initially positioned the antenna at the ISS for AOS when it came into range. Since the software decided the antenna would pass through a North/South stop point, it decided the rotor would need reversed 180 degrees and the antennas would need to be flipped 180 degrees to avoid passing through a North/South stop point. This was indeed a lesson from the school of hard knocks, but we averted disaster. If we had advanced the computer clock to test the antenna system beforehand, we would have known this would have happened. You can never perform too much testing.

We had a computer serial port start to give us trouble on my second ARISS event. It would disappear from time to time so I decided to use a USB to Serial adapter to work around the problem. The adapter solved the unstable port issue and eliminated one less thing to give us trouble in the future.

All 3 of the ARISS school events I supported were a complete success. Each of the 3 schools (Walter Jackson Elementary School, Rainbow Middle School, and Pinson Valley High School) completed all 20 of their questions. During the last 2 ARISS events I supported we could have easily asked 5 – 10 more questions. It is far better to have more talk time than leaving any student standing with no time remaining.

Dealing with the Press

The press can be a great opportunity to extend a message about ARISS, Amateur Radio, and AMSAT. Make sure you understand what each organization does and provide web link information for people to contact those organizations. The press is a great opportunity to publicly thank all of those who were involved in the event and let the community know this type of event is open for all who submit a proposal. You never know who will receive that message and what they will do with it.

Tell Somebody about your experience

Once you have completed an ARISS activity you need to go tell somebody about it. Chances are you will be asked to tell others about the event at local Amateur Radio Club meetings and Hamfests. If not, reach out to Amateur Radio Clubs in your area and spread the excitement. Let other schools know they can do the same thing at their school. The problem is generally the knowledge of where to go find the information. One of the schools I worked said they would have never found out about some of the grant money available to them if it had not been for hosting the ARISS event at their school.

DXing the Kuiper Belt

Radio Communications at the edge of the Solar System

Daniel Schultz N8FGV

A copy of the slides will be posted after the symposium at
https://www.qsl.net/n8fgv/New_Horizons_at_Ultima_Thule.pdf

On New Year's Day skip the Rose Bowl Parade, watch us on NASA TV!

For Further Reading

Chasing New Horizons: Inside the Epic First Mission to Pluto
by Alan Stern and David Grinspoon ISBN- *9781250098962*
https://www.amazon.com/Chasing-New-Horizons-Inside-Mission/dp/1250098963

APL New Horizons official public website:
http://www.pluto.jhuapl.edu

The Planetary Society
http://www.planetary.org

The New Horizons Kuiper Belt Extended Mission
S.A. Stern, H.A. Weaver, J.R. Spencer, H.A. Elliott, New Horizons Team
https://arxiv.org/abs/1806.08393

NASA Deep Space Network
https://deepspace.jpl.nasa.gov

Deep Space Network NOW - current operating status of the DSN
https://eyes.nasa.gov/dsn

Deep Space Communications and Navigation Center of Excellence
https://descanso.jpl.nasa.gov

Telecommunications Link Design Handbook
https://deepspace.jpl.nasa.gov/dsndocs/810-005
Module 203, Sequential Ranging
Module 214, Pseudonoise and Regenerative Ranging

Delta Differential One-way Ranging
https://deepspace.jpl.nasa.gov/dsndocs/810-005/210/210A.pdf

Consultative Committee for Space Data Systems
https://ccsds.org

1992 QB1: The first Kuiper Belt object opened a realm of 1,000 Plutos
http://www.astronomy.com/year-of-pluto/2015/06/1992-qb1-the-first-kuiper-belt-object-opened-a-realm-of-1000-plutos

To Pluto by way of a postage stamp
https://ntrs.nasa.gov/search.jsp?R=19950056267

The following papers may require subscriptions to access, ask your librarian:

The Pluto system: Initial results from its exploration by New Horizons
Science 16 Oct 2015: Vol. 350, Issue 6258, DOI: 10.1126/science.aad1815
http://science.sciencemag.org/content/350/6258/aad1815

The small satellites of Pluto as observed by New Horizons
Science 18 Mar 2016: Vol. 351, Issue 6279, DOI: 10.1126/science.aae0030
http://science.sciencemag.org/content/351/6279/aae0030

The atmosphere of Pluto as observed by New Horizons
Science 18 Mar 2016: Vol. 351, Issue 6279, DOI: 10.1126/science.aad8866
http://science.sciencemag.org/content/351/6279/aad8866

Operations Challenges for Missions with Significant Round-Trip Light Times
Kathryn Bechtold, Sarah Bucior, Rebecca Sepan, Sun Matsumoto
https://arc.aiaa.org/doi/abs/10.2514/6.2010-2166

New Horizons and the Pluto flyby: A flight control team's story
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https://arc.aiaa.org/doi/10.2514/6.2016-2461

The Radioscience Experiment on New Horizons
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https://ieeexplore.ieee.org/abstract/document/6051216

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G.L. Tyler, I.R. Linscott, M.K. Bird, D.P. Hinson, D.F. Strobel, M. Pätzold
Space Science Reviews (2008) 140: 217–259.
https://link.springer.com/article/10.1007%2Fs11214-007-9302-3

Preparing and Implementing the New Horizons Uplink Occultations: Applying Concepts, Tools, and Lessons Learned Over Nearly a Decade of Flight
Rebecca L. H. Sepan, Florilda C. Baker, Ivan R. Linscott, Kamal Oudrhiri
https://arc.aiaa.org/doi/10.2514/6.2016-2537

The RF telecommunications system for the New Horizons mission to Pluto
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https://ieeexplore.ieee.org/abstract/document/1367922

First deep-space flight demonstration of regenerative pseudo-noise ranging
Christopher B. Haskins, Dennis J. Duven, Christopher C. DeBoy, J. Robert Jensen
https://ieeexplore.ieee.org/document/6187117

Flexible coherent digital transceiver for low power space missions
C.B. Haskins, W.P. Millard, J.R. Jensen
https://ieeexplore.ieee.org/abstract/document/1655851

Doppler Correction and Tracking in Commercial NGSO Networks

Brennan Price, N4QX[1]

Introduction

Operators in the amateur-satellite service are well versed with non-geostationary orbit (NGSO) satellites; with few exceptions, the amateur fleet since OSCAR 1 has exclusively comprised satellites intended for low-earth, medium-earth, and high-earth orbits (LEO, MEO, and HEO, respectively).[2] In contrast, commercial fixed-satellite and broadcast services have traditionally been provided via geostationary orbit (GSO) satellites. While there are established commercial NGSO constellations in the mobile-satellite service for telephony and narrowband data (including, notably, Iridium and Globalstar), GSO systems have historically been the backbone for the current generation of high-throughput satellite networks. A successfully deployed GSO system eliminates the need for the ground user at the Earth station to track the satellite while in orbit, and the constant azimuth and elevation of the satellite with respect to each Earth station eliminates the necessity to correct for Doppler during operation.

While these are advantages of GSO satellite networks, there is an inherent disadvantage imposed by the laws of physics: Even at the speed of light, it takes about one-half second to complete the two hops (user-to-gateway and gateway-to-user) necessary to transmit and receive information to and from the network. While the GSO model continues to provide advantages for applications that are not latency-sensitive, the demand for low-latency high-throughput satellite applications has driven a great deal of interest in NGSO commercial satellite constellations. The FCC has processed or is considering a number of applications for NGSO constellations in the K_a-band and above, and the proposed size of these constellations varies widely.[3]

NGSO systems have predominated in the amateur-satellite service for a variety of reasons, including ease and expense of launch, and the inherent ability of an NGSO satellite to be used at all locations over which the satellite footprint passes (albeit for a small amount of time). The LEO case also offers the advantage of lack of noticeable latency. But amateur satellite operators are familiar with the slight drawbacks: the necessity to correct for Doppler shift throughout a pass, and the need to track the satellite across the sky, most often by mechanically moving an antenna through an arc during a pass. While "duly authorized persons interested in

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[2] Of the two exceptions, one satellite failed to reach the intended geostationary orbit (OSCAR IV), and the other is pending launch (Es'hailsat 2).

[3] FCC applicants for NGSO system licenses or landing rights include Boeing, WorldVu Satellites Limited ("OneWeb"), Viasat, Theia, Audacy, Telesat, SpaceX, O3b, Karousel, Kepler, LeoSat, and Space Norway. Space Norway's application for a constellation of a few HEO spacecraft with apogee above the arctic region was quickly granted by the FCC. The remaining applications are for constellations that are exclusively or predominately comprised of MEO or LEO spacecraft.

radio technique solely with a personal aim"[4] may welcome the challenge of correcting for Doppler and tracking satellites in order to learn about these facets of satellite operation, these techniques would not likely be welcome to a commercial consumer of broadband or other services provided through an NGSO satellite network. It is necessary to automate these processes in the commercial environment. While this automation is still being perfected, a number of established technical and operational procedures are expected to play a role.

Doppler Correction

Readers of AMSAT's seminal operating publication *Getting Started with Amateur Satellites* are familiar with the One True Rule of Doppler correction: "each operator tunes his transmit frequency, corrected for Doppler, so that it arrives at the same frequency *at the spacecraft* . . . ."[5] Similarly, the downlink frequency is adjusted so that the corresponding transmission *from the spacecraft* is received.[6] The One True Rule is best practice in the commercial space as well, for basic spectrum management principles that become more pronounced as the transmission frequency increases.

When the speed of a space station relative to an Earth station is small compared to the speed of the radio wave (and it always is), the Doppler shift observed may be approximated by the formula:

$$\Delta f = \frac{\Delta v}{c} f_0$$

where Δf is the deviation from the frequency at the satellite f_0, Δv is the relative velocity between the space station and the Earth station, and c is the speed of light. Operators in the amateur-satellite service are familiar with the Doppler deviations in the range of a few to dozens of kilohertz for V, U, and L band operation. Compared to L band, the deviation on K_a band will be about 23 times as pronounced, all other factors being equal. Assigning each user terminal a transmission channel with a guard band for Doppler at each end results in inefficient use of spectrum; a different correction protocol is required to permit channels to be packed together within the satellite passband.

Amateur-satellite service implementation of the One True Rule has traditionally been accomplished via computer-aided tuning techniques. These techniques could be used in the commercial setting, but another method has involved the use of a control channel on each transponder, which each end user terminal will identify. A control channel at a known nominal frequency observed by a user terminal at an offset frequency allows the user terminal to calculate the Doppler correction at any given time without reference to Keplerian elements. The control channel will also carry data assigning a portion of the transponder to each user terminal, and the user terminal adjusts its transmissions to arrive at the space station within the assigned portion of

[4] ITU Radio Regulations, Article 1.56 (definition of amateur service, incorporated by reference in Article 1.57, definition of amateur-satellite service).
[5] Alan Biddle, WA4SCA, *Bringing the One True Rule of Doppler Tuning into the 21st Century*, as reproduced In G. Gould Smith, WA4SXM, *Getting Started with Amateur Satellites*, 2018 ed., at A-3 (emphasis in original).
[6] *Id.*

the transponder. This approach to Doppler correction, relying on observed control signals from the satellite rather than calculations based on Keplerian elements, has been long documented and used in mobile-satellite service networks comparable to the Globalstar and Iridium constellations.[7]

Tracking Techniques

User equipment in NGSO satellite systems ideally does not use mechanical means to track a target satellite as it moves across the sky. Such an approach adds to the user's power budget and maintenance commitments. Non-mechanical antennas, such as "egg beaters", have been used in the amateur-satellite service to access NGSO satellites, but antennas of this type are not suitable for use in commercial services, which have antenna performance standards requiring narrow beamwidths to avoid interference issues with other satellites in the target constellations, other NGSO constellations, and GSO satellite networks.

It is anticipated that commercial NGSO user equipment will utilize phased array antennas pointed toward the sky. These computer-controlled arrays of antennas create beam by activating only certain antenna elements at the same time, resulting in transmit and receive patterns that can be electronically steered to point in different directions without moving the antennas. Phased arrays are not new, but their use is becoming more prevalent in both satellite and terrestrial communications to facilitate the exploitation of millimeter waves.[8] The FCC rules for Earth stations in motion in GSO networks in the fixed-satellite service have recently been revised to account for the shift from mechanical to electrical beam forming.

Phased arrays have certain limitations, namely that the ability to form an antenna pattern to specification fails below a certain elevation angle. NGSO systems will compensate for that limitation by having constellations large enough to permit communication with at least one satellite above that level.

Conclusion

Successful implementation of Doppler correction and satellite tracking in commercial NGSO applications requires an automated solution that is transparent to the end user. The amateur-satellite service pioneered the concept of One True Rule, and commercial systems are designed to implement this rule by adjusting in response to an observed downlink signal. Phased arrays are the likely solution for space station tracking by user equipment, and the limitations of these arrays will be compensated for by constellation size, ensuring access to at least one NGSO satellite above a certain elevation angle. In time, these techniques may come to be considered in the amateur-satellite service as well, although manual correction and tracking remain valuable for their illustration of radio principles, one of the foundations of the amateur-satellite service.

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[7] Qingchong Liu, *Doppler Measurement and Compensation in Mobile Satellite Communications Systems*, MILCOM 1999: IEEE Military Communications, Conference Proceedings (Oct. 31-Nov. 3, 1999) (*abstract available at* https://ieeexplore.ieee.org/document/822695?partnum=822695&searchProductType=IEEE%20Conferences&_ga=2.94393692.1735695680.1540306295-1274502560.1540306295).

[8] For a discussion of a radio amateur's contributions to terrestrial phased array and propagation research, *see* Thomas Gallagher, NY2RF, *47 GHz—Out There on the Edge*, *QST*, Sep. 2016, at 9.

Volunteer For AMSAT

AMSAT needs qualified volunteers for a number of positions

If you want to be a part of the team that is keeping Amateur Radio in Space and to work toward designing and building satellites and finding launches, WE NEED YOU! No pay but a great deal of satisfaction in knowing that you are helping make something happen. We need people with a wide range of technical and non-technical skills.

Satellite Development Technical Experience

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- Power systems design
- RF and microwave systems design
- Attitude determination and control
- Orbital mechanics, orbit determination and mission planning
- Orbital debris mitigation
- Radiation effects mitigation and mission assurance
- Internal Housekeeping Unit (IHU) systems, command, and control hardware
- IHU software design and development, real time operating systems
- Software Defined Radio and Digital Signal Processing
- Embedded programming and FPGA development
- PC board layout and construction
- Systems engineering
- Test planning and system testing
- Mechanical design and construction, machine shop work, CNC and 3D printing
- Technical writing and illustration, CAD design software
- Logistics, parts procurement, inventory and distribution
- Ground station hardware and software development

If you have hardware or software technical skills, and proven experience directly applicable to satellite design, please contact the AMSAT Vice President of Engineering.

Due to International Traffic in Arms Regulations (ITAR), positions involving space flight hardware or software require US citizenship or permanent resident status. Ground station development is open to all qualified persons regardless of citizenship.

ARISS Development and Support

AMSAT's Human Space Flight Team is looking for volunteers to help with development and support of the Amateur Radio on the International Space Station (ARISS) project.

- ARISS hardware development for space flight and ground stations
- ARISS technical mentors to assist with scheduled school contacts

AMSAT Educational Relations

AMSAT's Educational Relations Team needs volunteers with a background in education and classroom lesson development.

- Engage the educational community through presentations of how we can assist in teaching about space, radio, electronics and other STEM subjects in the classroom.
- Create scientific and engineering experiments packaged for the classroom.
- Create methods to display and analyze experimental data received from satellites.

AMSAT News and Communications

- Join the AMSAT News Service (ANS) team as a weekly editor on a rotating schedule reporting on amateur radio in space and related activities.
- Assistant Editor for the AMSAT Journal magazine working with authors, columnists and members developing and publishing print articles on amateur radio in space and related activities.

Communications through the AMSAT News Service and AMSAT Journal are essential in keeping both our members and the wider public informed. If you have good communications skills and are interested, please contact AMSAT Communications Volunteer Coordinator.

General AMSAT support

- Web design and maintenance
- Video recording, digital conversion and editing
- Write technical or instructional material
- User services, Field Operations

AMSAT is an organization of self starters. While we sometimes have tasks which we can assign, our most important contributions come from someone who sees a need, has the skills to solve the problem, and then goes ahead and does so. So pick an area that you think needs improvement and explain what you will do to make it better.